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PRODUCED BY MODIFICATIONS IN THE MOLECULAR CONCENTRATION OF THE EXTERNAL MEDIUM

BY

G. G. Scott

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A PHYSIOLOGICAL STUDY OF THE CHANGES IN *MUSTELUS CANIS* PRODUCED BY MODIFICATIONS IN THE MOLECULAR CONCENTRATION OF THE EXTERNAL MEDIUM[1]

BY G. G. SCOTT

(*Presented by title before the Academy, 10 March, 1913*)

CONTENTS

[1] Submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, in the faculty of Pure Science, Columbia University.

Introduction

Differences in osmotic pressure have been held to explain many physiological processes. It is a great temptation, for example, to ascribe the passage of materials into and out of the cell to differences in molecular concentration between the cell contents and the circulating medium; and yet, such a process as the secretion of urine is not satisfactorily explained by the physical theories of osmosis and diffusion. It does not necessarily follow, however, that, because these theories in our present state of knowledge fall short of a complete explanation of physiological processes, they should on that account be altogether discarded, nor should this be taken as an argument for vitalism. The full understanding of both the physical process and the associated chemical process would make clear the physiological process. So that everything that can be ascertained with regard to the passage of materials through membranes is of value to the science of physiology.

A common method of determining the osmotic pressure of a solution is by means of a determination of its freezing point. The degree of depression of the freezing point of the solution below that of pure water is proportional to the osmotic pressure of the solution. The amount of the depression of the freezing point, or Δ, is usually obtained by the use of the Beckmann apparatus. The form of apparatus that was used in the determinations described in this paper was made by Goetz of Leipzig. When in constant use at low temperature, there is a tendency toward a slight re-arrangement of the molecules of the glass tube, and this results in a contraction that is sufficient to introduce a slight error in the readings. It is therefore advisable for any one working with this instrument to make frequent determinations of the freezing point of pure water. In the experiments here described, this procedure was followed and the proper correction was always made in the calculations.

Various aspects of the osmotic relations of the body fluids of aquatic animals to the surrounding medium have been fruitfully investigated. The waters of the earth differ in their molecular concentration. Fresh water contains but a very small amount of salts in solution. The water of the ocean, with a specific gravity of 1.025, contains about 3.0 per cent of salts in solution. The water of the Black Sea and the Baltic Sea contain less salts than the water of the ocean because of the great influx into them of river water. The Mediterranean and Red Seas on the other hand contain more salts in solution than ocean water because of the excess of evaporation over the inflow of fresh water. There is considerable variation in the osmotic pressure of the body fluids of animals that inhabit these various waters. For example, the blood of fresh water invertebrates and fishes is much more concentrated than the water in which they live. While the body fluids of these forms is maintained at a constant osmotic pressure, the surrounding water is by no means isotonic with the blood serum. The Δ of fresh water is 0.025°, while that of the blood of fresh water fishes is about 0.60°. The blood of marine invertebrates and elasmobranch fishes has about the same molecular concentration as that of the sea. The mean Δ of the waters of the Mediterranean Sea and the mean Δ of the body fluids of the invertebrates and elasmobranch fishes which inhabit it is 2.29°. The Δ of the water of the ocean is about 2.00° and invertebrates inhabiting such waters have a similar Δ. In the case of the elasmobranchs, it has been claimed that the surrounding medium is isotonic with the blood. On the other hand, the Δ of the blood of marine teleosts is less than one-half that of the external medium. For example, although the Δ of sea-water from the Baltic is 1.80°, according to Dekhuysen ('04) the Δ of the blood of marine teleosts from these waters is only 0.724°. The Δ of the blood of fresh water fishes is nearly the same as that of the marine teleosts. The blood of other marine vertebrates, such as chelonia and cetacea, and of the other fresh water and land vertebrates is similar in its osmotic pressure to that of the marine teleosts.

In view of the fact that the elasmobranchs constitute the highest group to possess blood and other body fluids with an osmotic pressure near to that of sea-water, it appeared to the present writer that an extensive investigation should be made of the effects of changes in the molecular concentration of sea-water upon the blood and other tissues of the elasmobranchs. Since a dilution, rather than a concentration, of the sea-water would be the modification of the external medium to which these fishes might be subjected in a state of nature, more attention was given to the effect of dilutions of the external medium.

In physical experiments of an osmotic nature, two solutions are separated by a membrane and the qualitative relations of the process by which the fluids pass through the membrane is studied. In the present investigation, the membrane with which we have to do is possibly one or any combination of three living structures which separate the living substance of the body from the sea-water. These three structures are: *a*, the skin of the body; *b*, the mucous membrane of the enteric canal; *c*, the membrane of the gills. In the following pages, these will be termed the limiting membranes of the body. Outside of these membranes is the sea-water. Within the body, the rapidly circulating blood comes into such relation with sea-water as to insure the exchange of gases. It is a common belief that, by virtue of these structures alone, the organism is maintained in osmotic equilibrium with the surrounding medium. How far is this position tenable?

The relation of each of these structures to the solution within and without the organism may be that of a freely permeable membrane, a semi-permeable membrane or an impermeable membrane. The limiting membranes of the marine invertebrate body have been shown to be quite freely permeable. Sea-water is isotonic with its blood; but if the sea-water is diluted, salts leave the body by way of these structures, and water from without enters into the body with the result that the blood soon attains the same molecular concentration as the outside medium. Similar adjustments are said to take place in the case of the elasmobranchs. In this case, however, it is claimed that the resulting equality is attained not by the loss of salts from the body but by changes in the relative amount of water in the blood. Further investigation of this matter seems necessary. In addition the following questions call for investigation. What are the lethal limits of departure from the normal osmotic pressure of the blood of elasmobranchs? Is the modification in the osmotic pressure of this blood dependent upon the time of immersion in the changed external medium? Is the change dependent upon the degree of change in the osmotic pressure of the external medium? Does a lethal change in the osmotic pressure of the blood affect the corpuscles? If so, in what manner and to what degree? What is the effect of the modified blood upon blood pressure, heart beat and respiration? Is there any evidence of a mechanism for the maintenance of the normal osmotic pressure of the blood? Is there any evidence that a new and permanent normal osmotic pressure of the blood is established under conditions in which the concentration of the external medium is permanently modified? Does the blood of the elasmobranch under such conditions remain of the same molecular concentration as that of the modified external medium? Evidence on these and related problems is offered in the present paper.

The experiments described below were carried on at the Biological Laboratory of the United States Bureau of Fisheries at Woods Hole, Massachusetts, and at the New York Aquarium. I wish to thank the Commissioner of Fisheries, the Hon. George M. Bowers, Dr. Francis B. Sumner and Mr. T. E. B. Pope for the many facilities extended at Woods Hole, and to extend thanks likewise to Dr. Charles H. Townsend, the

Director of the New York Aquarium. I must also express my indebtedness to Professors Frederic S. Lee and F. H. Pike of the Department of Physiology of Columbia University for many helpful suggestions.

Historical

Sumner ('06) published a brief summary of investigations of the osmotic relations of the body fluids of aquatic animals to their surrounding medium. Bottazzi ('07) has given an extensive review of the literature bearing on this subject. I will limit this synopsis, therefore, to a brief statement of investigations on the osmotic relations of the elasmobranchs to the surrounding medium. Constant reference will be made to investigations on other forms in the pages that follow.

Mosso ('90) observed that elasmobranchs died very soon after being placed in fresh water. He explained the death as being due to the fact that the erythrocytes were laked by the influx of fresh water into the capillaries of the gill membranes, that the capillaries were clogged up with these broken down corpuscles, that circulation was thus stopped and that death ensued from asphyxiation. Von Schroeder ('90) found a large amount of urea, 2.6 per cent, in the blood and other tissues of the normal dog-fish. Quinton ('90) confirmed this statement of von Schroeder's. Rodier ('00) found at Arcachon on the southwest coast of France that the Δ's of the blood serum of different species of elasmobranchs were similar, although slightly lower than that of the sea-water in which they lived. The pericardial, peritoneal and uterine liquids had the same Δ as the blood serum. He also corroborated the discovery of von Schroeder as to the presence of urea in the blood of elasmobranchs and called attention to its rôle in determining the osmotic pressure of the blood. He found that the bile and urine contained less chlorine than the blood. Fredericq ('04) confirmed Rodier's statement with regard to the rôle of urea in maintaining the osmotic pressure of the blood. He found that if one puts a dog-fish, *Scyllium,* into concentrated or diluted sea-water, equilibrium between the osmotic pressure of the internal medium and the external medium takes place in a short time, due to the withdrawal or addition of water from the blood without involving the dissolved substances of the blood. Garrey ('05) found that the blood of the elasmobranchs from Woods Hole is isotonic with the sea-water and that dilution or concentration of sea-water causes a similar change in the blood of selachians immersed in such modified media, but that death ensues before an equilibrium is established. He concluded that the limiting membranes of the selachian body are semi-permeable. Bottazzi ('06) showed that not only the blood but also the urine, uterine fluid and the bile of the cartilaginous fishes are isotonic with the sea-water. It should be noted here that the Δ of the sea-water at Naples, where Bottazzi worked, is much greater than that at Arcachon and Woods Hole, where Rodier and Garrey respectively worked, and yet the blood of the elasmobranchs from all three regions is approximately isotonic with the surrounding medium. Bottazzi ('08) came to the conclusion that the urea, found in such large quantity in the blood, is formed by the muscles. Baglioni ('05) corroborated von Schroeder's '90 statement with regard to the urea in selachian blood. He also found that the elasmobranch heart would continue to beat if filled with a solution of equal parts of urea and sodium chloride, to which a trace of calcium salt was added. Dakin ('08) found marked changes in the osmotic pressure and chlorine content of the blood of the dog-fish when the animal was immersed in fresh water. One of his general conclusions is that the limiting membranes of the body are impermeable to salts and that the changes observed in the blood are due to variations in the relative amount of water. The limiting membranes of the body are semi-permeable. Hyde ('08) found that injection of solutions of sodium, calcium, potassium and magnesium salts in different degrees of dilution produced changes in the blood pressure and the respiratory and cardiac activity.

Osmotic Pressure of the Blood of *Mustelus canis* under Normal Conditions

Emphasis is often placed upon the constant value of the osmotic pressure of mammalian blood. Yet Findlay ('05) calls attention to the fact that there are diurnal variations in the osmotic pressure of human blood. Thus he gives the Δ of human blood at 9 A. M. as 0.535°; at 12 M. as 0.558°; at 1.30 P. M., after dinner, as 0.585°, and at 5.45 P. M. as 0.528°. Bottazzi ('06) found that the Δ of the blood and body fluids of marine invertebrates in the neighborhood of Naples fluctuated between 2.195° and 2.36°. He also found a similar range in the depression of the freezing point of the sea-water. Rodier ('00) working at Arcachon on the southwest coast of France found that the Δ of the waters from the laboratory basin varied between 1.87° and 1.95°, while the water from the ocean itself was more constant, having Δ's ranging from 2.05° to 2.09°. Rodier in describing the Bay of Arcachon said: "Its waters have a density, salinity and osmotic pressure always less than sea-water, and varying with the season, height of tide, place from which the water was taken, depth of water and time of day." Rodier found that the freezing point of the blood serum of different species of selachians was near to that of their sea-water medium, although in many cases it was 0.04° to 0.05°

lower. He concluded that they had not become acclimated to the more dilute bay water. Bottazzi ('06) found that the Δ of the blood of *Scyllium stellare* varied from 2.31° to 2.42°. He recorded the Δ of the blood of *Trygon* as 2.378°, while Mosso recorded it as 2.44°. Bottazzi ('06) found the mean Δ of the blood of elasmobranchs at Naples to be 2.356°, although the mean Δ of the sea-water was 2.29°. Yet Bottazzi concluded that the osmotic pressure of the blood of cartilaginous fishes is similar to that of the marine invertebrates in being identical with that of the sea-water. Garrey ('05) noted variations in the Δ of the sea-water at Woods Hole and variations also in the Δ of the blood of elasmobranchs. The mean Δ of sea-water was 1.82°, while that of the elasmobranchs he studied was 1.88°.

I have noted at different times the following Δ's of the sea-water in the laboratory of the Fisheries station at Woods Hole, namely: 1.76°; 1.78°; 1.79°; 1.80°; 1.83°; 1.855°; 1.87°. The average of these is 1.81°+. The Δ's of eighty specimens of *Mustelus* taken from the sea-water of the laboratory basin at various times proved to be as follows:

TABLE I.—*Distribution of the freezing point of the blood of eighty specimens of Mustelus canis*

Number of specimens	Δ	Number of specimens	Δ	Number of specimens	Δ
1	1.71°	7	1.83°	6	1.90°
1	1.74	7	1.84	5	1.91
1	1.76	5	1.85	9	1.92
1	1.78	4	1.86	6	1.93
1	1.79	4	1.87	2	1.95
5	1.80	6	1.88	1	1.99
3	1.81	2	1.89	1	2.03
2	1.82				

The mean depression of freezing point of the blood of the eighty specimens is 1.869°. Garrey recorded a mean value of 1.88°. But the mean Δ does not give a proper conception of the fluctuation in the osmotic pressure of the blood. It is possible that the extremes of this series represent abnormal fishes. Greene ('05) found a decrease of 32 per cent from the normal Δ of the blood of the Chinook salmon in the case of an old weak male and attributed this extreme variation to the pathological condition of the specimen. On referring to the above table, it will be seen that the greater number of Δ's range between 1.80° and 1.93°. The distribution of Δ's between these points is, with the exception of those at 1.92°, quite uniform. The average Δ is just about midway between these two points. There are about as many Δ's one side of the mean point as on the other side. The mean Δ of *Mustelus* blood is .05° lower than the sea-water in which it lives. It has already been noted that Rodier ('00) observed the same fact in connection with the elasmobranchs at Arcachon. The observations of Bottazzi ('06) reveal the same relationship. Finally, Garrey's '05 data agree nearly with mine.

The small difference between the Δ of the blood and that of sea-water is important in that the molecular concentration of the blood of elasmobranchs is only approximately equal to that of the sea-water. According to the above table, the blood of *Mustelus* can pass with entire safety through a range of at least 0.15° in its osmotic pressure.

Changes in the Osmotic Pressure of the Blood due to Alterations in the Density of the External Medium

preliminary study

It has been shown by a number of investigators that the osmotic pressure of the internal body fluids of the marine invertebrates depends upon the molecular concentration of the surrounding medium. Fredericq ('04), Garrey ('05) and Dakin ('08) have shown that this is true to a certain degree of the elasmobranchs. Fredericq concluded that a new equilibrium was established when he put *Scyllium* into diluted or concentrated sea-water. For example, he put *Scyllium* into diluted sea-water having a Δ of 1.67° for twenty-seven hours, at the end of which time the Δ of its blood serum was 1.70°. Another specimen was put into concentrated water having a Δ of 2.72° for twenty-four hours, when the Δ of the blood was 2.70°. Garrey ('05) found that the blood of *Mustelus canis,* though normally having a mean Δ of 1.88°, changed to 1.45° after an hour's immersion in fresh water. Dakin ('08) found that when the spiked dog-fish, *Acanthias vulgaris,* and the skate, *Raia clavata,* were put into fresh water, there was a considerable fall in the osmotic pressure of the blood. The mean Δ of these forms was 1.90°. In the four hours during which the dog-fishes were in fresh water, the Δ of the blood changed to 1.435°, showing a rise in the freezing point of 0.465° from the normal condition. The three specimens from which the above results were obtained were nearly dead at the end of the experiment. The change in the blood of the skate was not as great. This form was nearly dead at the end of two hours' immersion in fresh water, at which time the Δ of the blood was 1.645°, showing a rise in the freezing point of .255°. In these experiments of Garrey and Dakin, death took place before a new osmotic equilibrium was established. I determined to ascertain whether there was any relation between the duration of immersion in modified solutions of sea-water and the change in the osmotic pressure of the blood. The form used was *Mustelus canis.* As brought into the laboratory, the fish were placed in a large tank of sea-water. The salt water supply was then shut off and a stream of fresh water was turned into the tank. In a few minutes the water in the tank was fresh. After certain periods of immersion, the specimens were removed and a small quantity of blood was drawn from the caudal artery of each for a freezing point determination. It will be noted in the experiments that follow that the normal Δ of the blood of each animal is not given. But one freezing point determination was made in each case and that at the end of the time of immersion in the experimental medium. It should be borne in mind, however, that the mean Δ of the normal blood of *Mustelus* is about 1.87°. The results of the first experiment are as follows:

TABLE II.—*Change in the freezing point of the blood after various periods of immersion in fresh water*

(Δ of fresh water = 0.025°)		
Specimen	Immersion time in minutes	Δ of blood
1	35	1.62°
2	40	1.565
3	60	1.585
4	60	1.610
5	75	1.495
6	90	1.54

Individual changes in the freezing point of the blood are not the same for the same time of immersion. In a general way, however, the osmotic pressure becomes progressively less as the time of immersion increases.

I next concluded to ascertain the relation of change in the freezing point of the blood to solutions less dilute than fresh water. In the second experiment a solution of one-half sea-water and one-half fresh water was employed. The Δ of this solution is about 0.90°. The results are as follows:

TABLE III.—*Showing the change in the freezing point of the blood after various periods of immersion in one-half sea-water and one-half fresh water*

Specimen	Immersion time in minutes	Δ of blood
1	50	1.77°
2	75	1.705
3	100	1.685
4	200	1.595
5	245	1.555

In the third experiment a solution of three-fourths sea-water and one-fourth fresh water was used. The following results were obtained. The Δ of this solution is about 1.35°.

TABLE IV.—*Showing the change in the freezing point of the blood after various periods of immersion in three-fourths sea-water and one-fourth fresh water*

Specimen	Immersion time in minutes	Δ of blood
1	30	1.77°
2	60	1.74
3	100	1.73
4	230	1.64

Both solutions cause a rise in the freezing point of the blood. Yet the rise is greater in the more dilute solution. On comparing the effects of the two solutions, it is seen that the same changes in the freezing point are produced in a shorter time in the second solution than in the third solution. A similar effect is produced in still less time in the first solution, fresh water, than in the second one, which is one-half fresh water and one-half sea-water.

The effect of concentrated solutions of sea-water was next measured. Two such solutions were employed: one with a specific gravity of 1.035 and a Δ of 2.60°; the other with a specific gravity of 1.040 and a Δ of 3.15°. The results were as follows:

TABLE V.—*Showing the change in the freezing point of the blood after various periods of immersion in concentrated solutions of sea-water*

Solution A—Sp. Gr. = 1.035 Δ = 2.60°		
Specimen	Immersion time in minutes	Δ of blood
1	30	2.075°
2	50	2.115
3	75	2.185
Solution B—Sp. Gr. = 1.040 Δ = 3.15°		
Specimen	Immersion time in minutes	Δ of blood
1	35	2.10 °
2	45	2.16
3	85	2.175

In both of the solutions more concentrated than sea-water there is a lowering of the freezing point of the blood, an effect which is just the opposite of that produced by fresh and dilute solutions. The initial effect is greater in the more concentrated solution, although the final effect is about the same.

Although in each of the five experiments the normal Δ of each specimen as taken from sea-water is not known, the results indicate that the degree of change in the osmotic pressure of the blood depends upon the molecular concentration of the external medium. The results differ from those of Fredericq, in that they show that the osmotic pressure of the blood does not become equal to that of experimental media that differ markedly from the medium to which the animals are normally adapted. Attention is again called to the different degree to which the individual animals respond to modifications in the concentration of the external medium. Some die sooner than others in these abnormal media. Hyde ('08) observed that the effects of operation varied in different skates. For example, Hyde noted that when the same operation was performed upon two animals apparently in every respect alike, in the one case the effects might be momentary, while in the other they might be severe and prolonged.

CHANGES IN THE OSMOTIC PRESSURE OF THE BLOOD FROM THE NORMAL CONDITION UNTIL NEAR DEATH IN FRESH WATER AND CONCENTRATED SEA-WATER

Green ('05) found that the chinook salmon, *Oncorhynchus tschawytscha,* in its migrations to the head waters of rivers for spawning, underwent a permanent decrease of 17.6 per cent in the concentration of its blood and yet was able to carry on with vigor the activities of its muscular and nervous system. How far may this decrease proceed before death takes place? He found that the blood serum of an old weak male salmon showed a decrease of 32 per cent from the mean Δ of the blood serum of normal salmon. This represents the maximum of dilution of which the blood is capable while still maintaining life. I concluded to investigate this question in the case of the dog-fish, *Mustelus,* and at the same time to study the progressive osmotic changes of the blood from normal life to death in fresh water and concentrated sea-water. Cessation of breathing was taken as an index of death.

The following technique was employed: The spinal cord of the animal was exposed from the dorsal aspect, at the junction of the caudal fin with the trunk of the body. In this way no large blood vessel was interfered with. The cord was then destroyed by a probe as far forward as the anterior dorsal fin. Hyde ('08) has shown that all the centers governing respiration in the skate, though of a segmental nature, are located in the medulla. Since in the above operation only the posterior two-thirds of the cord was destroyed, the nervous structures that govern respiration were not affected.

After the cord was destroyed, the tail was removed, the caudal artery and vein being thus exposed. Blood was then taken for the determination of its freezing point. After this, the caudal artery was closed with a small wooden plug covered with absorbent cotton. The animal with the exception of the posterior part of the body was then placed in the tank containing the experimental solution. After the desired time, a second sample of blood was taken for a second determination of its freezing point. The difference between the first and the second was a measure of the change in the osmotic pressure of the blood of the particular animal for the given time and the given solution. In a number of cases as many as six samples of blood, usually about 5 c. c. each, varying with the size of the fish, were taken from one specimen. The blood was drawn into a small beaker and placed in an ice bath until the caudal artery of the fish could be closed and the fish could be transferred back to the water. The common freezing tube with the side neck for the insertion of an ice crystal was not used on account of the large amount of blood that would thus be necessary for each determination. A test tube with a smaller diameter was used instead. Duplicate determinations of the freezing point of the blood and distilled water demonstrated that the error due to undercooling must have been small. The experiment was repeated in a number of cases with uniform results, as will be shown later. Several clean dry test tubes were kept at hand in order to facilitate the determination of the freezing point of a number of samples in the shortest space of time. I found that about fifteen minutes were required for all the steps in the making of a single determination. On account of necessary interruptions, it was not possible to make the time intervals equal in all cases.

The whole blood, including corpuscles and plasma, was used in the experiments that follow. Hamburger ('95), Roth ('99) and others have asserted that the corpuscles are inert in determinations of the freezing point. Moore ('08) found that the corpuscles of pig's blood had a Δ of from 0.02° to 0.03° lower than that of the serum. Since in all the following experiments Δ was obtained in the way already indicated, the error due to the presence of corpuscles would be approximately constant in cases where the corpuscles were not laked. It would have been practically impossible to make the frequent determinations of Δ in these experiments, had I stopped in each case to defibrinate and centrifuge each sample of blood. The results are as useful for purposes of comparison as if the blood had first been defibrinated and then centrifuged. Time was saved by omitting these procedures and I believe that the results are as satisfactory. The actual pressure in atmospheres can be easily found by

$$\text{multiplying } \Delta \text{ by } \frac{22.4}{1.85} \; (=12.108).$$

EFFECT OF FRESH WATER

After the first sample of blood was taken, the animal was placed in a tank of sea-water, into which fresh water was then run, so that in a few minutes the water in the tank was fresh. The results of this experiment were obtained from a series of ten fishes, six males and four females, ranging from 61 to 82 centimeters in length, and are shown in Table VII.

TABLE VII.—*Changes in the freezing point of the blood of Mustelus canis after immersion in fresh water until nearly dead*

Sex	Length in cm.	Weight in grams	Immersion time in minutes	△ of blood	Change in △ of blood
♀	79	1588	0	1.93 °	0.000 °
			15	1.905	0.025
			30	1.805	0.125
			45	1.705	0.225
			60	1.630	0.300
			73	1.600	0.330
♂	64	822	0	1.81	0.000
			25	1.805	0.005
			60	1.530	0.280
			80	1.380	0.430
♀	69	1021	0	1.88	0.000
			40	1.73	0.150
			65	1.64	0.24
			90	1.435	0.445
♀	61	652	0	1.87	0.000
			20	1.81	0.06
			45	1.64	0.23
			60	1.50	0.37
♂	82	2211	0	1.880	0.000
			15	1.855	0.025
			30	1.79	0.09
			45	1.71	0.17
			60	1.61	0.27
♂	74	1134	0	1.880	0.000
			20	1.84	0.04
			40	1.74	0.14
			60	1.64	0.24
			80	1.38	0.50

TABLE VII.—*Changes in the freezing point*—(Continued.)

Sex	Length in cm.	Weight in grams	Immersion time in minutes	△ of blood	Change in △ of blood
♀	80	1687	0	1.890	0.000
			35	1.76	0.13
			55	1.605	0.285
			70	1.53	0.36
			85	1.39	0.50
♂	77	1502	0	1.900	0.000
			20	1.84	0.06
			40	1.74	0.16
			55	1.59	0.31
♂	79	1460	0	1.850	0.000
			15	1.81	0.04
			30	1.76	0.09
			45	1.635	0.215
			65	1.50	0.35
			75	1.40	0.45
♀	76	1304	0	1.920	0.000
			15	1.87	0.05
			40	1.74	0.18
			55	1.63	0.29
			70	1.47	0.45
			80	1.44	0.48

In averaging the results, we may divide the time into five periods of twenty minutes each, the first twenty minutes of immersion constituting the first period and so on. The average change during each period of immersion is as follows:

1st twenty minutes $= +0.050°$
2nd twenty minutes $= +0.133$
3rd twenty minutes $= +0.265$
4th twenty minutes $= +0.400$
5th twenty minutes $= +0.470$

The average of the ten maximum determinations is $+0.408°$.

As was found in the series of experiments described on page 9 there are indications here also of individual variations in the reaction of the fishes to the changed environment. Figure 1 is a curve which represents the course of the change in the depression of the freezing point and therefore a fall in the osmotic pressure of the blood from the beginning to the end of the experiment. This curve is derived from the values computed for each of the twenty minute periods. Certain features of this curve may be here pointed out. There is a slow change at the beginning of the experiment. This continues during the first two of the five periods of immersion. There is then a change in the slope of the curve, indicating more rapid changes in the osmotic pressure of the blood. Toward the end of the time, less rapid changes are again indicated. The ordinate which determines the last part of the curve is the average of but two determinations, because most of the animals died before the immersion of a hundred minutes. The ordinate at D more correctly represents the average condition at death. That part of the curve from N to D represents graphically the course of the change in the freezing point of the blood from the normal condition until near death in fresh water. It may be thought that the initial slowness of the changes in the osmotic pressure of the blood is due to the fact that the water is changing from salt to fresh during this period. The slowness, however, continues longer than the time required for the change from salt to fresh water. The period of acceleration may be due to the gradual failure of the defences of the organism. It is possible that the first part of the curve represents changes due merely to the entrance of water into the blood of the animal. From this point of view, the second part of the curve might indicate the passage of dissolved substances such as salts out from the blood through the limiting membranes of the body into the water outside while the outside water continued to pass into the blood. This would mean, of course, profound changes in the physico-chemical constitution of the organism. Dakin ('08) found that the maximum change in the freezing point of the blood of three specimens of *Acanthias vulgaris* after immersion in fresh water until near death was 0.465°. Garrey found the maximum change in the freezing point of the blood of one *Mustelus* to be 0.37°. My observations range from 0.27° to 0.50°. That the magnitude of the change is not due to the amount of blood taken is shown from the records of specimens 1 and 2. The maximum change in case of No. 1 is .33°, while that of No. 2 was .43°, though six samples of blood were taken from the first specimen, while but four samples were taken from the second specimen. Other cases of the kind can be found.

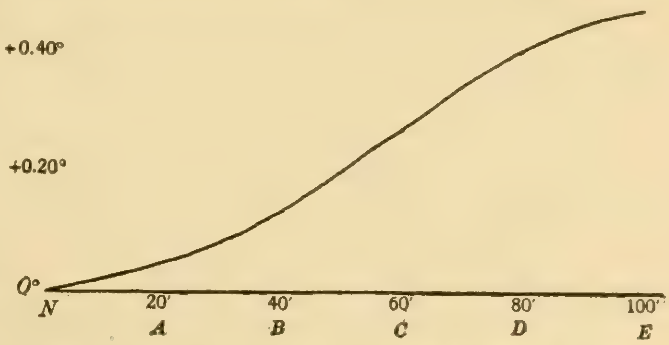

FIG. 1.—*Change in Δ of blood of Mustelus due to immersion in fresh water until death*

EFFECT OF A CONCENTRATED SOLUTION OF SEA-WATER

The change in the osmotic pressure of the blood from the normal condition until death in a concentrated solution of sea-water was next obtained. The procedure was in the main as before. The tank in which the specimens were placed after the operation contained about twenty-four liters of sea-water. To increase the amount of salts in solution in this sea-water, about 500 grams of sea-salt were dissolved in a jar containing eight liters of sea-water. This was placed above the tank. After the normal sample of blood was obtained, the specimen in each case was placed in the tank of sea-water and the concentrated solution from the jar was at once run into the tank at one end, the overflow running out at the other end. At the same time, the various samples of blood were obtained for the determinations of the freezing point, the specific gravity of the water in the tank was taken. On the whole, the specific gravity of the solution was 1.034+. Its Δ was about 2.60°. The Δ of the sea-water was about 1.82° and its specific gravity, 1.025. An analysis of the chlorides in both sea-water and in water of the concentration attained at the end of each of these experiments showed that the latter contained about 33 per cent more salts than sea-water. The water in the tank reached this concentration in about fifteen minutes after each experiment began. The results are given in Table VIII. Data with regard to eleven specimens are shown, seven females and three males, ranging in length from 67 cm. to 84 cm. The sex of one animal was not recorded.

TABLE VIII.—*Changes in the freezing point of the blood of Mustelus canis after immersion in a concentrated solution of sea-water until near death*

Sex	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Change in Δ of blood
♀	80	1531	0	1.84°	0.000°
			17	1.90	0.06
			30	1.96	0.12
			48	1.99	0.15
			65	2.06	0.22
			77	2.08	0.24
♀	80	1361	0	1.84	0.000
			20	1.93	0.09
			35	2.01	0.17
			50	2.05	0.21
			65	2.11	0.27
			80	2.15	0.31
♂	75	1247	0	1.88	0.000
			25	1.94	0.06
			40	2.00	0.12
			55	2.07	0.19
			75	2.10	0.22
♀	67	950	0	1.80	0.000
			15	1.87	0.07
			30	1.94	0.14
			50	2.00	0.20
			65	2.08	0.28

TABLE VIII.—*Changes in the freezing point*—(Continued.)

Sex	Length in cm.	Weight in grams	Immersion time in minutes	△ of blood	Change in △ of blood
♂	76	1332	0 15 30 45 60	1.84 1.86 1.91 1.99 2.02	0.000 0.02 0.07 0.15 0.18
♂	76	1417	0 10 30 45 60	1.89 1.95 2.01 2.07 2.09	0.000 0.06 0.12 0.18 0.20
♀	84	1531	0 20 40 60 80	1.83 1.92 1.96 2.01 2.08	0.000 0.09 0.13 0.18 0.25
♀	74	1162	0 12 25 40 55	1.93 2.00 2.07 2.11 2.17	0.000 0.07 0.14 0.18 0.24
♀	79	1446	0 20 35 45 65	1.94 2.02 2.07 2.15 2.15	0.000 0.08 0.18 0.21 0.21
	75	992	0 15 30 50 65	1.92 2.02 2.06 2.11 2.18	0.000 0.10 0.14 0.19 0.26
♀	76	1219	0 15 35 60 75	1.90 1.96 2.01 2.08 2.15	0.000 0.06 0.11 0.18 0.25

Dividing the above time into four periods of twenty minutes each and averaging the change in the freezing point of all the specimens for each period, we have the following values:

1st twenty minutes = 0.074°
2nd twenty minutes = 0.125
3rd twenty minutes = 0.190
4th twenty minutes = 0.260

The average of the eleven maximal changes is 0.24°. Figure 2 is a curve which represents the course of the change in the blood from the normal condition until near the death of the animal in the above concentrated solution. Since the curve shows a progressive lowering of the freezing point of the blood, it should be interpreted as showing an increase in the osmotic pressure of the blood. There is a slight falling off in the effect after an initial sudden change in the freezing point. Toward the end of the time of immersion the change is more rapid again.

There is good evidence for believing that the dog-fishes in their migrations up and down the coast wander into brackish waters. The organism must be adapted therefore to withstand a moderate amount of decrease in the density of the external medium. Under natural conditions, however, the organism is never subjected to such a concentrated solution as was used in the present experiment. The concentrated salt solution may act as a chemical stimulus upon the arterioles of the gills, causing them to dilate, and thus bringing about a greater influx of blood to the gills, from the capillaries of which the blood would lose water rapidly by osmosis. After the initial stimulus, the arterioles would recover their tone, there would be a decreased amount of blood sent to the gills and the loss of water would be retarded. The more rapid increase in Δ toward the end of the period is evidently an index of greater changes in the physico-chemical constitution of the organism.

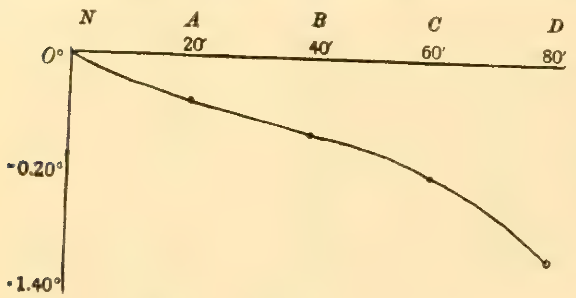

FIG. 2.—*Change in Δ of blood of Mustelus due to immersion of fish in a hypertonic solution of sea-water until death.*

The above results as to the effect of fresh water and concentrated sea-water on the osmotic pressure of the blood show that, at the time of death in fresh water, there is an average rise in the freezing point of the blood of 0.41° and, at death in the above concentrated solution, a fall of 0.24°, *i. e.*, in the osmotic pressure a reduction of 21.9 per cent and an increase of 12.8 per cent respectively. The values probably represent the lethal limits of departure from the normal constitution of the blood within which protoplasmic activities of this form take place. I must differ from Fredericq and others who would classify the elasmobranchs with the marine invertebrates as to the osmotic relations of their body fluids to the external medium. This conception would imply that the degree of change in the osmotic pressure of the blood is equal to the degree of change in the osmotic pressure of the external medium. In the case of *Mustelus*, we have seen that this is not true. It may be, however, that some relationship exists between the osmotic pressure of the blood of the elasmobranchs and modifications in the molecular concentration of the sea-water. Fresh water has a Δ of about 0.025°. This is about 1.795° less than that of sea-water. The concentrated solution had an average specific gravity of about 1.034+. The Δ of such a solution was about 2.60°, which is 0.78° greater than that of sea-water. Since the fresh water produced an average rise in the freezing point of the blood of 0.41°, what would be the amount of change in the freezing point of the blood in the concentrated solution if the change in the blood depends upon the change in the molecular concentration of the external medium? We can formulate the following proportion: 1.795° : 0.41° :: 0.78° : X, where X should equal the change in the blood due to the concentrated solution should the above relation hold true. X equals 0.177° or approximately 0.18°; but the observed maximum change in the concentrated solution was 0.24°. There is a difference between the two values of 0.06°. This would indicate that the relation is only roughly if at all proportional. If the changes took place to a different degree or in a different manner in the two solutions, of course any close relationship would be modified.

Furthermore, do these results show any relation between the degree of change in the freezing point of the blood and the time of immersion? In the fresh water experiment, eight records were taken between 40 and 45 minutes from the beginning. The average time was about 42 minutes. The average time of immersion of all ten fishes was 74 minutes. The average final change in the Δ of the blood was 0.41°. Therefore in the following proportion,—74 min. : 42 min. :: 0.41° : X, X should have approximately the same value as the Δ actually observed at the end of the 42 minute period. X equals 0.23°, the theoretical degree of change in Δ. The observed change in the Δ of the blood of the eight specimens after 40 to 45 minutes' immersion in fresh water was 0.18+°, showing that the observed change lacked 0.04+° of being as great as the calculated change.

The average time of immersion in the concentrated solution was 69 minutes. Six determinations were made at about 42 minutes from the beginning of the experiment. If the time relation holds in this case, then X in the following proportion should be similar to the observed change in Δ at the end of the 42-minute period: 69 min. : 42 min. :: 0.24° : X. But X equals 0.146°. The observed change in 42 minutes was 0.16°. One might conclude from the above considerations that we were dealing here with purely physico-chemical phenomena. It would be hazardous, however, to make any sweeping assertions. If we compare the changes in any individual with the average changes in the group, the simple relationships just suggested do not hold. The factors involved are so many and to such a degree unknown, that although, in the final analysis, the phenomena must be physical and chemical, we are not justified in maintaining that the relations are definitely quantitative.

Figure 3 represents in a graphic manner the relation of the osmotic pressure of the blood to the concentration of the external medium as based upon the conception of a proportional relation existing between the two. The abscissas represent freezing point determinations. The ordinates represent specific gravities of different solutions of sea-water. Pure

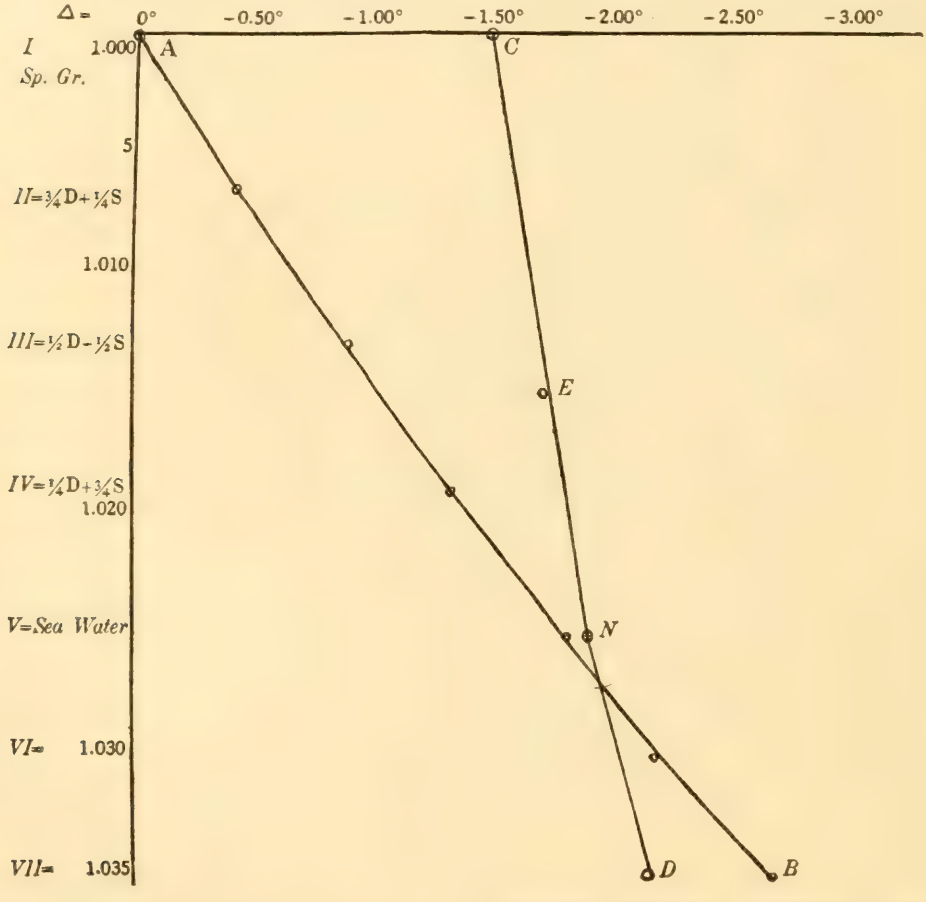

FIG. 3.—*Relation of the Δ of blood to Δ of different solutions of sea-water. Curve A–B = Δ's of solutions. Curve C–D = Δ's of blood*

water has a Δ of 0.00° and a specific gravity of 1.000. The curve A—B represents the freezing point of different dilutions of sea-water. This curve is constructed from freezing point data obtained from seven different dilutions of sea-water. These were as follows: I, pure water; II, three-fourths pure water plus one-fourth sea-water; III, one-half pure water plus one-half sea-water; IV, one-fourth pure water plus three-fourths sea-water; V, sea-water; VI, concentrated sea-water having a specific gravity of 1.030; VII, concentrated sea-water having a specific gravity of

1.034+. The curve C—D represents the freezing point of the blood at the different concentrations represented by the curve A—B. It is constructed by drawing a line through the following points: C = the Δ of the blood at the death of the organism in fresh water; N, the Δ of normal blood; D, the Δ of the blood at the death of the animal in the concentrated solution, having a specific gravity of 1.034+ and a Δ of 2.60°, the effect of which has been described in this section of the paper; E, the Δ of blood of *Squalus acanthias* in harbor water which has a Δ of about 1.00°.

A further account of this is given later (on page 31). That the operation of destroying the cord did not modify the results is strongly indicated by the following instance: A large *Mustelus canis* was operated on in an attempt to collect a sample of its urine. The spinal cord was destroyed in the manner already indicated. The abdominal cavity was opened, the rectum was ligated and a large glass tube was fastened in the cloaca. The animal was then placed on a support in the sea-water in such a way that the head as far back as the last gill slit was under water. The abdominal incision was closed and the surface of the body was kept moist with a cloth wet with sea-water. At the end of twenty-four hours the fish was still alive and breathing normally. When the pericardium was opened, the heart was seen to be beating regularly. Figure 4 is a record of the respiration at the end of twenty-four hours, the time record indicating intervals of two seconds. Although the experiment was a failure as far as its primary purpose was concerned, it proved that the above operation in itself is no cause of immediate death. Sheldon ('09) has found that *Mustelus* may live for a week after a similar destruction of the cord. Parker ('10) has called attention to "the ease with which this fish resists the adverse effects of operations."

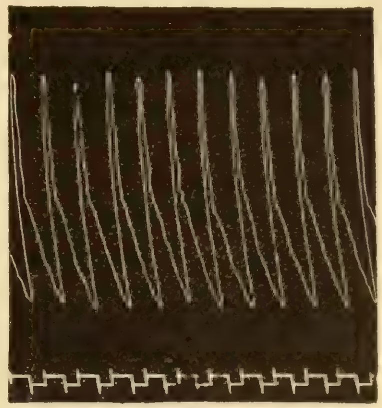

FIG. 4. — *Respiratory movements in Mustelus, 24 hours after destruction of spinal cord.*

In a series of earlier experiments, the results of which are given in Table VI, on the effect of immersion in fresh water on the freezing point of the blood, I first defibrinated the blood, then centrifuged it, and used the serum for the determination of the freezing point. About 10 to 15 c. c. of serum was used for each determination.

In these preliminary experiments, blood was drawn from each specimen but once. In the case of the specimens immersed in fresh water, the blood was drawn after they had been immersed for about an hour. The results were as follows:

TABLE VI.—*Showing the depression of the freezing point of the serum of Mustelus in salt water and after immersion in fresh water for one hour*

Serum from normal fishes		Serum from fishes immersed in fresh water one hour	
No. specimen	△	No. specimen	△
1	1.920°	1	1.580°
1	1.950	4	1.460
2	1.805	2	1.595
2	1.950	2	1.595
1	1.947	2	1.540
Average, 1.914°		Average, 1.554°	

The average rise in the freezing point of the serum of these dog-fish after immersion in fresh water for an hour is thus seen to be +0.36°.

CHANGES IN THE OSMOTIC PRESSURE OF THE BLOOD BROUGHT ABOUT BY A RETURN TO SEA-WATER AFTER IMMERSION IN FRESH WATER OR CONCENTRATED SEA-WATER

The above experiments on the effects of diluted and concentrated solutions of sea-water indicate that to cause a decrease in osmotic pressure with the diluted solutions there must be currents outward through the limiting membranes of the body; to cause an increase with concentrated solutions there must be currents inward. Is it possible to demonstrate these two effects in the same individual? If reversibility is possible, then after a fall in osmotic pressure resulting from immersion in a diluted solution of sea-water, the original pressure should apparently be gained when the animal is returned to normal sea-water. The experiments reported in Table IX were carried out to test this possibility.

TABLE IX.—*Effect on the blood of transference of Mustelus from sea-water to fresh water followed by subsequent return to sea-water*

Sea-water	Fresh water			Sea-water			
Normal △ of blood in degrees	Duration of immersion in minutes	△ of blood	Change from normal	Duration of immersion in minutes	△ of blood	Change from normal	Amount of reversal
1=1.835	35	1.620°	+0.215°	25	1.685°	+0.15 °	0.065°
2=1.895	55	1.655	+0.240	50	1.785	+0.115	0.125
3=1.875	30	1.675	+0.200	50	1.760	+0.115	0.085
4=1.905	25	1.665	+0.240	100	1.785	+0.120	0.120

It is clear that, after immersion in fresh water, we get as before a rise in the freezing point of the blood. After the return to sea-water, the Δ is lowered and the osmotic pressure is increased again; but the normal osmotic pressure of the blood is not regained, even though the return to sea-water is as long or even longer than the sojourn in fresh water. This is shown in the case of the fourth specimen; for after 25 minutes in fresh water the freezing point had been raised 0.24° above normal, but when the fish had been returned to sea-water for 100 minutes the freezing point was still 0.12° above normal. Figure 5 shows the changes in the Δ of the blood of this specimen. The fish was in fresh water from F to F^1 and in sea-water from F^1 to S. The base line represents the normal Δ; the abscissas, time in minutes, and the ordinates, the rise in the freezing point of the blood. At first one might conclude from these experiments that the limiting membranes were not as permeable in one direction as the other. A second experiment of this nature will be de-

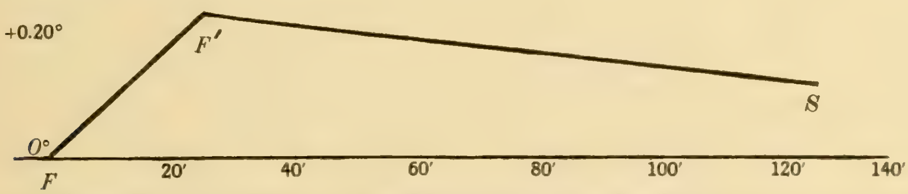

Fig. 5.—*Changes in Δ of blood of Mustelus due to immersion in fresh water followed by return to sea-water*

scribed. In this case, the mixed blood of the two specimens was used for the determination of the normal Δ, 1.895°. After 75 minutes' immersion in fresh water, there was noted a rise in the freezing point of the mixed blood of 0.245°. Both specimens were then returned to sea-water and one died soon after. A determination was made from the blood of the other 225 minutes after the return, and its Δ was 0.05° above the normal Δ. Although there was an apparent return to the normal condition, the animal was injured in some way, for it died soon after. In fact, it is not quite correct to assume that the normal condition of the blood was regained for the last figure given, *i. e.,* 0.05° is obtained by subtracting the final Δ of the blood of this fish from the Δ of the mixed blood of this fish and the other which died earlier. The number of molecules and ions in solution in the blood had decreased after immersion in fresh water. Certain parts normally present had escaped into the surrounding medium. The return of the organism to its normal medium did not suffice for the return to the blood plasma of the normal quantitative relation of parts in solution.

Concentrated solutions were also tried. Two such experiments will be described. In the first, three dog-fishes were used. The Δ of the combined blood of the three was 1.92°. They were then placed in a concentrated solution of sea-water having a Δ of about 2.60° for forty minutes, at the end of which time the Δ of the mixed blood from the three was 2.11°, the freezing point having fallen 0.19°. Then the specimens were returned to sea-water for eighty minutes, when Δ was 2.04°, showing that although the freezing point had risen 0.07°, it still lacked 0.12° of being normal. In the second experiment, three dog-fishes were also used. The normal Δ of their mixed blood was 1.87°. They were placed for sixty minutes in a tank containing a concentrated solution of sea-water having a Δ of about 2.15°. At the end of this time the Δ of their mixed blood was 2.00°, showing a fall in the freezing point of 0.13°. The three specimens were then returned to a concentrated solution having a Δ of 2.60° for sixty minutes more, at the end of which time the Δ of their combined blood was 2.18°, showing a total fall in the freezing point of the blood of 0.31°. Sea-water was then run into the tank for two and one-half hours, when the value of the Δ of the blood was 1.98°; that is in the two hours and a half after the return to sea-water the freezing point of the blood rose 0.20°, but was still 0.11° short of its value at the beginning of the experiment. Thus with neither a hypotonic nor a hypertonic medium did the organisms regain the normal Δ after the return to sea-water, even though they were kept in the sea-water as long or even longer than in the diluted or concentrated solution.

One other experiment of this nature will be referred to briefly. A somewhat small stream of concentrated sea-water was passed into the mouth and out through the gills of a large female dog-fish for 45 minutes. The Δ of its blood fell 0.09°. The small size of the stream possibly explains the small change in Δ. A stream of fresh water was then turned on gradually and Δ was again taken 60 minutes later. Δ proved to be 0.16° above its value in the concentrated solution and was even higher by 0.07° than the normal. The fish was then returned to sea-water for 60 minutes when Δ was 0.03° lower than the normal. In this case we have evidence of an increase in the osmotic pressure of the blood due to a concentrated external medium. A fall in the osmotic pressure results when the organism is subjected to a dilute external medium, after which it rises to the normal condition when the animal is returned to sea-water. It should be noted that, in changing the concentrated solution to fresh water, the concentrated solution was gradually replaced by fresh water and this in turn by the sea-water again. The fish was unusually large, being 120 cm. in length. It rested with its dorsal surface upon a support out of the water and the stream entered its mouth through a rubber tube having an inside diameter of about a centimeter. It seems to me that the normal Δ was regained in this case, because the external media produced but a small degree of departure from it. It is interesting to note that the maximum change produced in Δ is about equal to the normal range in Δ of normal dog-fish blood as described in the first section of this paper. The results with the other fishes indicate, however, that osmotic phenomena are complicated by the presence of other factors.

Rôle of the Gills in the Modifications

Considerable difference of opinion exists as to the part of the body that is concerned in the osmotic changes in the blood brought about by changes in the osmotic pressure of the surrounding medium. As stated above, there are three structures that may be the seat of this phenomenon, namely, the skin of the body, the lining of the alimentary tract and the gill membranes. Any one or all of these structures may be conceived to share in the above processes. The surface of the body of the dog-fish is covered with a closely associated system of dermal plates forming, with other structures of the skin, a tough coat through which it would appear that fluids could pass with the greatest difficulty if at all. The cells of the intestinal tract are known to exert a selective action on materials present in the intestine, and therefore we should expect that solutions more or less concentrated than sea-water which would possibly accompany the swallowed food would be passed out through the cloaca before osmotic changes of any account would take place. Furthermore, my observations indicate that the œsophagus and the cloacal aperture are kept closed during the greater part of the time, and are probably opened only during the taking in of food and the getting rid of waste. Therefore the wall of the gut would not ordinarily be exposed to solutions differing in density from that of sea-water, even though the whole fish were entirely immersed in such solutions.

The gills, however, are always freely exposed to the external medium. Each gill filament contains a fine capillary loop composed of an afferent vessel and an efferent vessel supported by connective tissue. Covering the capillary apparatus is an extremely thin epithelial membrane, so that there are but two thin layers of cells between the water and the blood stream, namely, the gill membrane and the endothelial wall of the capillary. If the rich capillary supply of the gills be taken into account, there is in effect a large, broad sheet of circulating blood separated from the water by an extremely thin membrane known to be permeable to gases. *A priori*, therefore, it would seem that the osmotic changes in the blood described above might take place through the gills.

The following views have been maintained with regard to this: Bert ('71) gave a minute description of the death of a fresh water fish in salt water. He described the gills as changing from bright red to dark red in color, and said that the congested condition of these membranes permitted the blood to transude through them. He found the corpuscles to be crenated, shriveled and piled up in masses in the capillaries. A tench suspended in a vessel of sea-water lived a long time if the head was kept out of the sea-water and the gills were bathed with fresh water. Fredericq ('04) stated, "I can in a short time change the proportion of salts in the blood of *Carcinas mœnas,* even to doubling the quantity, if I bring the animal into water more salty than sea-water. This is due to a peculiarly modified epithelium of the gill membranes by which substances dissolved in the water can go through the gills easily." With regard to the fishes Fredericq said, "Les vertèbres aquatiques des poissons se comportent tout differement. Chez eux, la branchie, si permeable aux echanges gazeux de la respiration, semple au contraire constituer une barrier presque infranchissable aux sels dissous dans l'eau de mer. La sang des poissons de mer n'est guère plus sale, au gout, que le sang des poissons d'eau douce." Quinton ('00), however, held the view that salts as well as water can pass through the external surface membranes of marine animals. In a later investigation by Bottazzi and Enrique ('01), it was shown that the stomach wall of the mollusk, *Aplysia,* is normally impermeable to salts. They concluded that the stomach wall is a semipermeable membrane, allowing the water to pass through but excluding the salts, and proposed the hypothesis that osmotic equilibrium is maintained by the liver, functioning as an organ of resorption. Siedlechi ('03) found that the stickleback, *Gasterosteus,* resisted the effects of sudden transitions from salt to fresh water and *vice versa.* This author held that the structure of the skin amply protects the organism from the effects of changes in the external medium. Schucking ('02) showed that salts left the body of *Aplysia,* though the mouth and anus were ligated. This result, together with those obtained by Quinton and Bottazzi, shows that the surface membranes of *Aplysia* are permeable. Overton ('04) concluded that the skin of amphibians is permeable to water and but slightly permeable to salts. Greene ('05) from his studies of the Chinook salmon inferred that in that species all three structures are impermeable. He accounted for the fall in the osmotic pressure of the blood at the spawning grounds as being due to absence of food and the poor physical condition of the fishes. Garrey ('05) tied off both ends of the alimentary canal of *Nereis* and *Chætopterus* and found that, if placed in fresh water, the animals swelled and increased in weight, which showed the permeability of the body wall to water. Garrey suspended *Limulus* so that the gills alone were immersed in a solution of one-half sea-water plus one-half fresh water. A decrease in the osmotic pressure of the blood took place which demonstrated the permeability of the gills.

Sumner ('06) inferred that the structure of the skin of most teleosts was an effective barrier to osmotic exchanges between the tissues of the fish and the external medium. He devised an apparatus by which the body was immersed in a solution of one concentration, while the gills were bathed by water of another concentration. In an experiment with the carp, *Cyprinus carpio,* the body of the fish was immersed in fresh water and sea-water bathed the gills. There was a loss of weight at the end of the experiment. In the second place, the body of this fresh water fish was immersed in sea-water and fresh water was supplied to the gills. The fishes not only continued to live longer than in the first instance, but there was no loss in weight. The result showed that no osmotic changes took place through the body membranes of the carp. When the body of the tautog, *Tautoga onitis,* a marine form, was immersed in sea-water and the gills were bathed with fresh water, the fishes died in from two to three hours. On the other hand, when the gills were supplied with sea-water and the body was immersed in fresh water, the fishes were apparently not affected. These ingenious experiments of Sumner, in which it will be noted that the fishes were not injured, contribute strong evidence for the conclusion that the gills alone are concerned in osmotic changes. Dakin ('08) called attention to the fact, as did Greene, in the case of the salmon, that while the contents of the stomach of the lump sucker are osmotically the same as sea-water, the osmotic pressure of the cœlomic fluid, though separated from the cavity of the intestine by a very thin wall, is the same as the osmotic pressure of the blood, which is much less than that of sea-water. He thus proved that the wall of the gut is normally impermeable to salts except in the processes of nutrition and was inclined to the belief that the membranes are semi-permeable.

From different points of view, the evidence indicates that the gills constitute the pathway by which the osmotic changes take place. Sumner alone has attacked the problem directly. Dakin criticised Sumner for not excluding the gut as a possible factor. I concluded to investigate this problem in the case of the dog-fish. The following facts justify Sumner's conclusion:

The average Δ of the blood of two dog-fishes immersed in fresh water for sixty minutes was found to be 1.597°. A male *Mustelus canis,* seventy-eight centimeters long, was pithed, the body cavity was opened, the œsophagus was ligated, and the fish was placed on a support out of the water. A stream of fresh water was then made to flow into its mouth and out through its gills. At the end of fifty minutes the freezing point of the blood of this specimen, whose gills alone were exposed to the fresh water, was 1.585°. As great a change had taken place in the osmotic pressure of its blood as had taken place in the case of those whose gills, intestinal wall and body surface were all exposed to the fresh water.

The operation on the five following specimens was similar to that on the preceding specimen. A stream of water was not conducted through the mouth, but the fishes were so placed on the support that the head as far back as the fifth gill slit was immersed in the water. In this manner, the œsophagus being ligated and the trunk of the body being out of water, the gills constituted the chief structures exposed to the experimental conditions. More than one determination of the freezing point was made in each case, the conditions of the experiments recorded in Table II being thus duplicated. These five specimens were also left in the fresh water until near death. The following, Table X, shows the results obtained from them:

TABLE X.—*Change in the osmotic pressure of the blood of Mustelus canis caused by immersion of the head alone in fresh water*

No.	Length in cm.	Weight in grams	Immersion time in minutes	△ of blood	Rise in △
1	80	1290	0 15 40 55	1.85° 1.68 1.52 1.37	+0.000° +0.17 +0.33 +0.48
2	77	1148	0 23 85	1.92 1.75 1.965	+0.000 +0.17 +0.455
3	79	1134	0 45 85	1.87 1.72 1.56	+0.000 +0.15 +0.31
4	86	2041	0 35 87	1.93 1.81 1.59	+0.000 +0.12 +0.31
5	80	1616	0 33 93	1.925 1.835 1.475	+0.000 +0.09 +0.45

The maximal changes in the freezing point of the blood in the case of the specimens belonging to Table VII, in which the three factors, body surface, intestinal wall and gills were exposed to fresh water, were, respectively: +0.33°, +0.43°, +0.445°, +0.37°, +0.27°, +0.50°,

+0.50°, +0.31°, +0.45°, +0.48°, the average being +0.41°. In the experiments shown in Table X the maximal rises were: +0.48°, +455°, +0.31°, +0.34°, +0.45°, the average being +0.407°. There is no marked difference in the changes in the two groups.

After about thirty minutes' immersion of the entire body in fresh water, the average maximum rise in the freezing point of the blood of three dog-fishes was +0.22°. The rise in two other specimens whose gills alone were bathed with fresh water for about the same time was +.247°, an unimportant difference. After the treatment with fresh water, all the specimens were transferred back to sea-water. The freezing point of the blood fell in each case. Moreover, the reverse change in the case of those fishes whose gills alone were exposed to the outside medium was 0.118°, while for those entirely immersed in fresh water the fall was 0.12°.

The average fall in the Δ of the blood of three specimens of *Mustelus* which were entirely immersed for forty minutes in a concentrated solution of sea-water having a Δ of 2.60° was 0.19°. The fall in Δ of one specimen with ligated œsophagus, the body surface out of water and the gills bathed with a hypertonic solution having a Δ of 3.15° for seventy-five minutes was 0.23°. The striking fact here is that the fall was no less in this specimen than in the others, in which all three structures were exposed to the experimental medium. The greater changes in the second case was due to the greater density of the external medium and the longer time of immersion.

In all the experiments described here, it will be noted that as great a change takes place in the osmotic pressure of the blood when the gills are the principal structures exposed to the experimental medium as when the gills, body surface and intestinal tract together are exposed. It is acknowledged that, with the gills, the outside membranes of the head and the lining membranes of the buccal cavity were exposed to the media. The surface membranes of the head are, however, excluded, inasmuch as the non-immersion of a much greater portion of the body surface made no difference in the results. It is extremely improbable that the lining membrane of the buccal cavity takes any part in the above changes, because of its histological structure and blood supply in comparison with the gill membranes. There is but one conclusion to be drawn. Osmotic changes which take place in the blood of *Mustelus canis* when the organism is surrounded by solutions more dilute or more concentrated than sea-water take place through the gill membranes.

Osmotic Pressure of the Blood of an Elasmobranch taken from Brackish Water

The dog-fishes probably migrate. I am informed by Mr. Denyse of the New York Aquarium that the spiny dog-fish, *Squalis acanthias,* is present in New York waters for a time during the latter part of May and the first part of June, and then disappears until the autumn, when it returns to remain until after the New Year. Observations are lacking during the mid-winter, as no fishing is done at that time, but for a number of weeks after the fishing is begun in the spring there is no sign of this species. Mr. Denyse informs me that the smooth dog-fish has been taken at some distance up the Hudson River. It is very probable then that in their migrations up and down the coast they pass the mouths of rivers in which the water must be brackish, especially in the spring time when the rivers are swollen with the spring freshets. Mr. Denyse has kept a daily record of the temperature and salinity of the water from New York harbor for the period from 1903 to 1911. From the monthly averages of that record, published in the Report of the Director of the New York Aquarium ('12), I have computed the average monthly specific gravity of the harbor water for the nine years in question. The results of this calculation are shown in Table XI.

Table XI.—*Average monthly specific gravity of New York harbor water for the years 1903–1911*[2]

Month	Specific gravity	Month	Specific gravity
January......	1.0139	July.........	1.0148
February....	1.0135	August	1.0154
March........	1.0121	September...	1.0155
April.........	1.0100	October......	1.0148
May..........	1.0120	November...	1.0147
June.........	1.0133	December....	1.0147

Although the migration of fishes is usually stated to be due to a search for better food conditions and for the purpose of spawning, there is a possibility that the non-appearance of *Squalus* in New York waters during the early spring is due to the dilute condition of the water. The density of the water is lowest during April. A considerable rise is noted in May and June, and it is then that these fishes make their first appearance.

These considerations lead to the question whether the dog-fish is sensi-

[2] From daily observations made by Mr. W. I. Denyse at the New York Aquarium.

tive to reductions in the density of the sea-water. Sheldon ('09) has contributed ample evidence of the great sensitiveness of various parts of the surface of its body to different chemical stimuli. The following instance is cited merely for the purpose of indicating an interesting problem for further investigation. At the New York Aquarium a tank about 250 cm. long, 35 cm. wide and 10 cm. deep was filled with harbor water. A very small *Squalus acanthias* about 35 cm. long, taken from harbor water, was placed in this tank. The brackish water continued to flow in at one end, while at the other end a stream of fresh water was run in. In a very short time the dog-fish turned about and swam to the end receiving the brackish water. It was then placed in the fresh water end, but swam again into the brackish water. After a number of trials, it was clear that the dog-fish was sensitive to the fresh water, as it persisted in seeking the saltier end of the tank. The nasal pouches were then packed with absorbent cotton and vaseline. The fish was again placed at various places in the tank, but swam about indifferently or remained stationary. Further investigation of this problem was not possible on account of the lack of proper facilities for experimenting with larger fishes.

The greater number of species of fishes on exhibition at the New York Aquarium are kept in the harbor water. What is the effect of such brackish water on the osmotic pressure of the blood of the elasmobranchs surviving it? Through the kindness of Dr. Townsend, the director, I was furnished with a number of dog-fishes, *Squalus acanthias,* for the purpose of securing an answer to the above question. At the time, the average specific gravity of the water was 1.015, which would correspond to a Δ of about 1.00°. The freezing point of the blood of seven fishes was as follows:

TABLE XII.—*Freezing point of the blood of Squalus acanthias from New York harbor water*

No.	Sex	Length in cm.	Δ of blood
1	..	56	1.70 °
2	♀	58	1.695
3	♂	38	1.70
4	♂	43	1.685
5	♂	41	1.695
6	♂	61	1.69
7	♂	61	1.66

The average Δ of the seven fishes was 1.69°. This value is 0.18° higher than the mean Δ of the blood of *Mustelus* in sea-water. At New York, I was unable to get a sample of the blood of *Squalus* as taken from full strength sea-water, *i. e.,* having a Δ of 1.82°. These dog-fishes are brought to the Aquarium from the fishing grounds near Sandy Hook. The Δ of the blood of two specimens from Vineyard Sound, Mass., was as follows:

a—female 56 cm. long, Δ = 1.81°.
b— " 49 " " " = 1.87°. Average = 1.84°.

This is not far removed from that of *Mustelus,* which is 1.87°. A larger number of determinations would probably average 1.87°.

Evidently the normal osmotic pressure of the blood of *Squalus* undergoes a reduction, when the fishes are kept in the harbor water. It is also of interest to see that the blood does not become isotonic with the brackish water in which the fishes are kept. There appears to be a new equilibrium. If we assume that the blood of *Squalus* has normally the same mean Δ as that of *Mustelus,* then we can conclude that the Δ of the blood of *Squalus* has risen 0.18°, due to the immersion in brackish water. Moreover this is the value to be expected, if the change in the osmotic pressure of the blood bears a definite relation to the change in the osmotic pressure of the surrounding medium. The following proportion shows this: 1.795° : 0.82° : : 0.41° : X, in which 1.795° equals the difference between the Δ's of sea-water and fresh water, 0.82° equals the difference between the Δ's of sea-water and harbor water and 0.41° equals the maximum change in the freezing point of *Mustelus* after immersion in fresh water. X, on the basis of the above theory, should equal the Δ of the blood of the fish after immersion in harbor water. But X equals 0.187°, whereas 0.18° was the observed change in Δ. It seems to me that the chief point of interest, however, is that the organism maintains an osmotic pressure of its blood greater than that of the water in which it is kept. From what is known of the marine invertebrates, this property of the dog-fish is a distinct advance. Many of the dog-fishes brought into the Aquarium do not survive. It is interesting to speculate as to why any survive. Is it because the limiting membranes of the body are more resistant, or do these membranes become more resistant in response to the change produced in the osmotic pressure of their blood? On immersion in fresh water, *Squalis* did not show as great a reduction in the freezing point of its blood as was the case with *Mustelus.* This is shown by the following table, XIII:

TABLE XIII.—*Change in Δ of blood of Squalus acanthias after immersion in fresh water for one hour*

No.	Length in cm.	Rise in Δ after 30 minutes in fresh water	Rise in Δ after 60 minutes in fresh water
1	56	+0.090°	+0.110°
2	58	+0.085	+0.160
3	61	+0.130	+0.260
4	61	+0.090	+0.130

The average change during the first half hour is +0.099° and at the end of an hour amounts to +0.165°. At the end of the same period in fresh water the blood of *Mustelus* had changed about 0.30°. At first it might be thought that the smaller change in the spiny dog-fish indicates an acquired immunity to the effects of dilute solutions of sea-water. It is possible that the limiting membranes of the body have become less permeable, thus preventing such a great change as in the blood of *Mustelus*, in the experiments with which the change in the external medium was greater. But, as was claimed above, the Δ of the blood of *Squalus* has risen 0.18°, due to the difference between the molecular concentration of sea-water and harbor water. Moreover the freezing point of its blood has risen an additional 0.16°, due to the transference of the fish from harbor water to fresh water. The total change is thus 0.34°, or nearly as great as that taking place in the blood of *Mustelus*, which was transferred directly from sea-water to fresh water. If this equality of modification in the osmotic pressure of the blood be true, then it follows that the limiting membranes of *Squalus* have acquired little or no resistance to the external medium; for their permeability has not changed. The change in the osmotic pressure of the blood is still proportional to the change in the osmotic pressure of the external medium. In Fig. 3, the point E, on line C—D, represents the Δ of the blood of *Squalus* from harbor water, which has a Δ of about 1.00°. Fig. 6 shows the changes in Δ of blood of *Squalus* due to immersion in fresh water. It will be noted that the initial Δ of the blood is .18° above the normal Δ of the blood in sea-water, and that although at the end of an hour in fresh water it has risen but 0.16°, yet it is 0.34° higher than the normal Δ in sea-water.

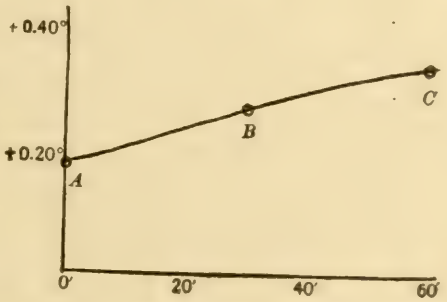

FIG. 6.—*Changes in the Δ of blood of Squalus due to transference from harbor water to fresh water. A, in harbor water; B, 30 minutes in fresh; C, 60 minutes in fresh.*

Effect of Loss of Blood on the Osmotic Pressure of the Blood of *Mustelus canis*

In the previous experiments, it will be noted that varying quantities of blood were taken for the determination of the freezing point. About five cubic centimeters were used for each determination, and as much as six times that quantity was taken from many of the specimens. The criticism might be brought that the loss of so much blood might have introduced a serious modification in the results, so that what we were attributing to the difference between the molecular concentration of the blood and the surrounding medium might in large part be due to loss of blood. It was necessary therefore to make a control experiment in which the conditions should be the same as those described on page 13, with the exception that the fishes should be immersed in sea-water during the entire period.

Fano and Bottazzi ('96) observed changes in the osmotic pressure of the blood of dogs associated with anemia produced by successive bleedings. They noted that the osmotic pressure of the blood fell immediately after the bleeding. They explained this as being due to a temporary lowering of the blood pressure, which causes a diminution in the elimination of salts ordinarily released in secretions. As a result, those processes which are concerned in the formation of lymph are depressed. The authors suggested that the rise in the osmotic pressure may be due to the abundance with which globulins are turned into the blood stream. Globulins passing from the tissues into a less concentrated serum dissociate themselves and separate from the bases with which they are combined and contribute these to increasing the concentration of the blood.

The work of these investigators is hardly applicable here, for the reason that they experimented upon dogs. They took proportionately larger quantities of blood than were used in the experiments upon the dog-fishes. Moreover, days and weeks elapsed between the periods when the blood was tested.

In each of the following cases, after the spinal cord was destroyed, the fish was placed in a tank of sea-water. Then samples of blood were taken at intervals for the freezing point determination. Results were obtained from nine fishes which ranged in length from 56 cm. to 124 cm. and in weight from 538 gm. to 6482 gm. For each freezing point determination, about five cubic centimeters of blood were taken from the smaller fishes and ten cubic centimeters from the larger. The entire amount of blood in mammals is stated to be one-thirteenth of the body weight. It is also known that a loss of one-half of this amount does not

TABLE XIV.—*Freezing point of the blood of Mustelus canis immersed in sea water*

No.	Sex	Length in cm.	Weight in grams	Time	△	Change in △	Estimated percentage of blood used
1	♂	58	538	3.50 P. M.	1.82°	0.000°	40
				4.30 "	1.82	0.00	
				5.20 "	1.80	+0.02	
2	♀	56	538	11.40 A. M.	1.87	0.000	55
				2.00 P. M.	1.84	+0.03	
				3.20 "	1.82	+0.05	
				4.55 "	1.84	+0.03	
3	♂	62	624	3.00 P. M.	1.835	0.000	50
					1.845	—0.01	
					1.835	0.00	
					1.840	—0.005	
4	♂	71	936	2.30 P. M.	1.84	0.000	32
				3.30 "	1.86	—0.02	
				5.55 "	1.84	0.00	
				6.25 "	1.88	—0.04	
5	♀	79	1474	11.10 A. M.	1.93	0.000	54
				11.50 "	1.93	0.00	
				2.30 "	1.91	+0.02	
				3.15 "	1.89	+0.04	
				4.30 "	1.88	+0.05	
6	♂	79	1588	3.20 P. M.	1.86	0.000	51
				4.00 "	1.90	—0.04	
				4.40 "	1.90	—0.04	
				5.20 "	1.90	—0.04	
				5.50 "	1.90	—0.04	
7	♀	84	1474	9.55 A. M.	1.81	0.000	67
				10.25 "	1.83	—0.02	
				10.55 "	1.83	—0.02	
				11.25 "	1.86	—0.05	
				12.00 M.	1.85	—0.04	
				3.00 P. M.	1.86	—0.05	
8	♀	112	4366	9.35 A. M.	1.81	0.000	18
				10.10 "	1.84	—0.03	
				11.00 "	1.85	—0.04	
				1.30 P. M.	1.86	—0.05	
				5.00 "	1.86	—0.05	
9	♀	124	6492	3.00 P. M.	1.84	0.000	28
				3.30 "	1.89	—0.05	
				4.00 "	1.90	—0.06	
				4.30 "	1.92	—0.08	
				5.00 "	1.92	—0.08	
				5.30 "	1.93	—0.09	
				7.00 "	1.92	—0.08	
				7.35 "	1.92	—0.08	
				8.00 "	1.92	—0.08	
				8.30 "	1.93	—0.09	

prove fatal. Hyde ('08) estimated that the blood of the skate is equal to one-twentieth of its body weight. Even if we assume that the total quantity of blood of *Mustelus* is equal to five per cent of its body weight, in none of the preceding experiments was one-half of the total blood of the body taken. Table XIV shows the results of the experiments in which the Δ's of the blood were obtained from different samples taken at intervals from the caudal artery of fishes immersed in sea-water.

In the above series of experiments, more blood was intentionally taken for each determination of Δ than was used in the preceding cases. As indicated above, the object of the experiments was to ascertain the effect of bleeding on the osmotic pressure of the blood. There was no difficulty in obtaining blood from any of the fishes experimented upon in the present connection. All were alive and breathing regularly at the time the last sample was obtained. The percentage of the total quantity of the blood given in each case is only a rough estimate based on the assumption that the total quantity equals five per cent of the body weight. In estimating this, the last sample was not included. In reviewing the results, it is to be noted that there is a slight rise in the freezing point of the blood of specimens 1, 2 and 5. The remaining six show a fall in the freezing point. On referring to the accompanying data in each case, it is found that the rise or fall in Δ is not related to the sex, length or weight of the fishes, or to the amount of blood taken. In many of the cases after the initial change, there is no further modification in Δ. It is possible that these small variations from the normal Δ are indications of the normal fluctuations in the osmotic pressure as maintained on page 6. The evidence presented in Table XIV is offered as further support for this conclusion. Finally, attention is called to the fact that the maximum changes are slight as compared with those recorded as due to the effects of fresh water and concentrated sea-water. On the whole we are justified in concluding that the effects recorded in Tables VII and VIII were due to the modifications in the molecular concentration of the external medium. Buglia ('08) found that simple bleeding produced in the physico-chemical properties of dog's blood variations absolutely negligible as compared with those obtained after injections of salt solutions hypertonic to the blood.

Additional Changes in the Blood Due to Alterations in the Concentration of the External Medium

CHANGES IN THE ERYTHROCYTES

One might conclude from the above changes in the osmotic pressure of the blood of fishes exposed to fresh water that the corpuscles were laked by the dilution due to the entrance of water into the blood and that this might be a contributing cause of death. In fact, Mosso ('90) working at Naples made this the basis of his explanation of the death of elasmobranchs under this condition. The freezing point of the sea-water from the Mediterranean is about 26 per cent lower than that of the water at Woods Hole. The degree of change to which the fishes were subjected when placed in fresh water was therefore greater in the case of the fishes with which Mosso worked. This difference may account in part for the divergence of my results from those of Mosso. Mosso stated that, if the tail of *Scyllium* was cut off after the fish had been in fresh water for half an hour, no more blood flowed from the artery, while the heart still continued to beat. On the other hand, I found that blood might be obtained from the caudal artery of *Mustelus* up to the point of death in fresh water, *i. e.,* from one to two hours. Mosso also claimed that the serum remained almost normal at the time of death in fresh water. We have here noted a profound lowering of the osmotic pressure of the serum. The results obtained by Garrey ('05), Dakin ('08) and myself show that this statement of Mosso's cannot be correct. Mosso believed the real cause of death to be due to suffocation. By the action of the fresh water, the red blood cells go to pieces and clog up the capillaries of the gills, thereby cutting off the exchange of gases in these structures.

Following up this hypothesis, Mosso studied the osmotic resistance which the red cells offered to different salt solutions. For example, the erythrocytes of selachian blood were destroyed in 2.5 per cent solutions of sodium chloride and the fluid soon became red. Teleosts like *Conger* and *Murœna* had a greater resistance and first lost their hæmoglobin in a 0.3 per cent NaCl solution. Mosso found that fresh water forms possessed blood more resistant to salt solutions of different dilution than marine teleosts, while anadromous fishes like *Anguilla* and *Acipenser* possess blood cells which are especially resistant to dilute salt solutions.

On account of the divergence between my observations and those of Mosso, I concluded to ascertain whether at the time of death as the result of immersion of *Mustelus* in fresh water its corpuscles were laked. This was ascertained in the following way: The spinal cord of a dog-fish taken from sea-water was destroyed. About ten cubic centimeters of blood were drawn from the caudal artery. This was closed, and the fish was transferred to sea-water which was rapidly changed to fresh. Near the time of death, the artery was opened a second time and a second sample of blood was obtained. Soon after each sample of blood was taken, it was defibrinated. Then each was placed in a separate centrifuge tube and the two were simultaneously centrifuged. At the end of this process, the serum of the normal blood was perfectly clear, while that of the other showed in some cases faint traces of laking. In other cases it was difficult to detect any such indication. On the whole, it was thus demonstrated that there was no marked laking of the corpuscles after immersion of the fish in fresh water.

In Fig. 7, N represents the osmotic pressure of the blood of *Mustelus,* in sea-water; F represents the osmotic pressure of the blood at the time of death in fresh water; while S represents the osmotic pressure of the first solution of NaCl in which the blood is laked. In solutions more concentrated than this the blood is not laked.

I made camera lucida drawings of the corpuscles from both fishes and observed no measurable differences in size. These corpuscles are oval and

FIG. 7. — *Diagram showing comparative Δ's of blood of Mustelus in sea-water, N; in fresh water, F; and of saline solution, S, in which blood is first laked.*

FIG. 8.—*Showing the difference between the ratios of volume of corpuscles to plasma in normal blood, N, as compared with blood taken from fishes after immersion in fresh water, H.*

flat, so that, in preparations made of them, the flat surface only would be observed and there would appear no indication of their thickness. It then occurred to me to make hæmatocrit studies of the blood under normal and experimental conditions. The following results were obtained. The ratio of the volume of corpuscles to that of serum of normal blood was found to be about 23 to 77, *i. e.,* the corpuscles form less than 25 per cent of the total volume of defibrinated blood. Blood from the same specimen near death after immersion in fresh water showed a ratio of 31 to 69, that is, the corpuscles occupied 31 per cent of the total volume of the defibrinated blood. In determinations made defibrinated blood in a graduated centrifuge tube, I found that in normal blood the ratio of corpuscle to serum was as 20.5 to 79.5. After immersion in fresh water the ratio was 30.77 to 69.23. Fig. 8 shows this difference. In this figure, N represents the ratio between the volume of corpuscles and serum in normal blood. H represents the ratio from blood taken from fishes after immersion in fresh water. Shaded portions represent corpuscles. Considering these results in connection with those obtained by the use of the camera lucida, we may conclude that at least some of the corpuscles are swollen after immersion of the fish in fresh water. The faint trace of laking at the end of the experiment indicates that at least some of these swollen corpuscles cannot withstand the increased pressure of distension by the absorption of water. These burst and cause the faint trace of laking noted above. In fact, in preparations made of the corpuscles of a fish that had died in fresh water, some corpuscles were found broken down.

Since Mosso claimed that the resistance of the erythrocytes of fishes varied in a general way with the salt content of the blood, I determined to ascertain the strength of solutions of NaCl which would cause the laking of the blood of elasmobranchs common at Woods Hole. He found that the erythrocytes of selachians at Naples were laked by solutions more dilute than 2.5 per cent NaCl. The sea-water from the Mediterranean is isotonic with a 3.8 per cent sodium chloride solution. A 2.5 per cent sodium chloride solution is about 34 per cent more dilute than the water from the Mediterranean. A reduction of 34 per cent in the salinity of the sea-water from Woods Hole would give a solution isotonic with 1.2 per cent solution of NaCl. So that according to Mosso's hypothesis the blood of the Woods Hole elasmobranchs should be laked in a 1.2 per cent solution of NaCl and in all solutions more dilute than this. I made up ten solutions of NaCl. The first was a 2 per cent solution, the second a 1.8 per cent solution, the remaining solutions decreased respectively 0.2 per cent, the last being a .2 per cent solution. I tried the effect of these solutions on the defibrinated blood of the smooth dog-fish, *Mustelus canis*, the spiny dog-fish, *Squalus acanthias*, the sand shark, *Carcharias littoralis*, and the skate, *Raia erniacea*. Following are the results of the experiments:

Experiment 1. *Squalus acanthias*. Male. 29 inches long.

No laking in 2 per cent NaCl to 1.0 per cent NaCl. Faint trace in 0.8 per cent NaCl. Decided in 0.6 per cent NaCl.

Male. 19+ inches long.

Same results as above.

Experiment 2. *Mustelus canis*. Male. 29 inches long.

No laking in 2 per cent NaCl to 1.2 per cent NaCl. Faintest trace in 1 per cent NaCl. Decided in 0.8 per cent NaCl.

Male. 29 inches long.

Results same as above.

Experiment 3. *Carcharias littoralis.* Female. 48 inches long.
No laking in 2.0 per cent NaCl to 1.2 per cent NaCl. Faint trace in 1.0 per cent NaCl. Decided in 0.8 per cent NaCl.

Experiment 4. *Raia erinacea.* Female. 20 inches long.
No laking in 2.0 per cent NaCl to 1.2 per cent NaCl. Faint trace in 1.0 per cent NaCl. Decided in 0.8 per cent NaCl.

It is clear that Mosso's statement is not applicable to the elasmobranchs from the Woods Hole region. In the case of the four species here indicated, there is no laking down to the 1.0 per cent NaCl solution and even this dilution does not decidedly lake the blood. Bottazzi ('06) found that the blood of elasmobranchs at Naples was more resistant than Mosso claimed; the first solution to lake the corpuscles was approximately a 2.0 per cent to 1.75 per cent solution of NaCl. Rodier ('99) found that elasmobranchs at Arcachon lost the hæmoglobin of their corpuscles in less dilute solutions than Mosso found to be the case with the elasmobranchs at Naples. Bottazzi ('06) explained this difference as being due to the difference in the salinity of the water at the two places. Thus the Δ of the sea-water at Naples is 2.29°, while the Δ of the sea-water at Arcachon is 2.00°. The average concentration of the laking solutions at Arcachon was 1.46 per cent NaCl. It appears that the corpuscles of the elasmobranchs at Woods Hole are much more resistant than those at Naples or at Arcachon, and more resistant than can be accounted for by the difference in the salinity of waters. Rodier ('99) believed that the urea in elasmobranch blood had something to do with the difference in the hæmolytic relations of elasmobranch and teleost blood; but Bottazzi ('99) found that even in a 6 per cent solution of urea which is almost isotonic with the blood the corpuscles lost their hæmoglobin. He came to the conclusion that in addition to the osmotic pressure exerted by the substances dissolved in the blood each of these substances and especially the sodium chloride exerted a specific chemical effect upon the corpuscles, thus maintaining their integrity. I made up a second series of solutions containing the same percentage of sodium chloride as the preceding series, but in addition each solution contained as much urea as NaCl, for the reason that elasmobranch blood contains about the same amount of urea as salts. In each case the corpuscles appeared at first sight to be more resistant in the solution of NaCl and urea than in the NaCl solutions. This is as follows:

Mustelus canis—Corpuscles laked in 0.8 per cent NaCl and 0.6 per cent NaCl + urea.

Squalus acanthias—Corpuscles laked in 0.6 per cent NaCl and 0.4 per cent NaCl + urea.

Carcharias—Corpuscles laked in 0.8 per cent NaCl and 0.6 per cent NaCl + urea.

It is of interest to note that the Δ of the 0.8 per cent NaCl solution is 0.50°, while that of the 0.6 per cent NaCl + urea solution is 0.56°; that is, the molecular concentrations of the two are quite similar. The Δ of the 0.6 per cent NaCl solution is 0.39° and that of the 0.4 per cent NaCl + urea solution is 0.38°. In other words, the osmotic pressures of the two solutions which first cause laking are in each case similar. The urea in the second set of solutions merely raises the osmotic pressure to the osmotic pressures of the solutions of NaCl. It must be concluded that, since the urea takes the place of the NaCl in these dilute solutions, at least neither the NaCl nor the urea exerts any specific chemical effect upon the corpuscles. The fact that such a great reduction in the osmotic pressure of the external medium is necessary before the hæmolysis of elasmobranch blood shows that the integrity of the corpuscle does not depend upon the equality of osmotic pressures between corpuscle and plasma. The corpuscles maintain their integrity even though there is a fall of over 40 per cent in the osmotic pressure of the surrounding medium. We have seen above that Mosso concluded that the resistance of the erythrocytes of the blood varied in a general way with the salt content of the blood. Since the blood of marine teleosts contains very much less salt than that of elasmobranchs, we should expect that teleost corpuscles would be much more resistant than those of elasmobranchs. Mosso found this to be true of the teleosts studied by him. My results differ in some respects from those of Mosso. The teleosts studied by me show but a small increase in the resistance of their corpuscles over that of the elasmobranchs which I examined. This is shown by the following results:

Experiment 5. Weakfish, *Cyonoscion regalis.* Female. 30 inches long.
No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laking decided in 0.6 per cent NaCl.
Female. 20 inches long.
Same results as above.

Experiment 6. Scup, *Stenotonus chrysops.* 8 inches long.
No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Distinct in 0.6 per cent NaCl. Decided in 0.4 per cent NaCl.

Experiment 7. Killifish, *Fundulus heteroclitus.* About twenty specimens used.
No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laked in 0.6 per cent NaCl.

Experiment 8. Flounder, *Pleuronectes.* Female. 15 inches long.
No laking in 2.0 per cent to 0.8 per cent NaCl. Faint in 0.6 per cent NaCl. Distinct in 0.4 per cent NaCl.

Experiment 9. Mackerel, *Scomber scombrus.* 10 inches long.

No laking in 2.0 per cent to 0.8 per cent NaCl. Distinct in 0.6 per cent NaCl. Decided in 0.4 per cent NaCl.

Experiment 10. Butterfish.

No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laked in 0.6 per cent NaCl.

According to Rodier and Quinton the blood of marine teleosts contains about 0.6 per cent salts, while that of elasmobranchs has about 1.7 per cent. I have found that the blood serum of *Mustelus* contains .86 per cent Cl, while that of the blood of the flounder, *Pleuronectes,* a marine teleost, has .53 per cent Cl. The equivalent in NaCl for the dog-fish is 1.42 per cent, while for the flounder it is 0.87 per cent; and yet we have

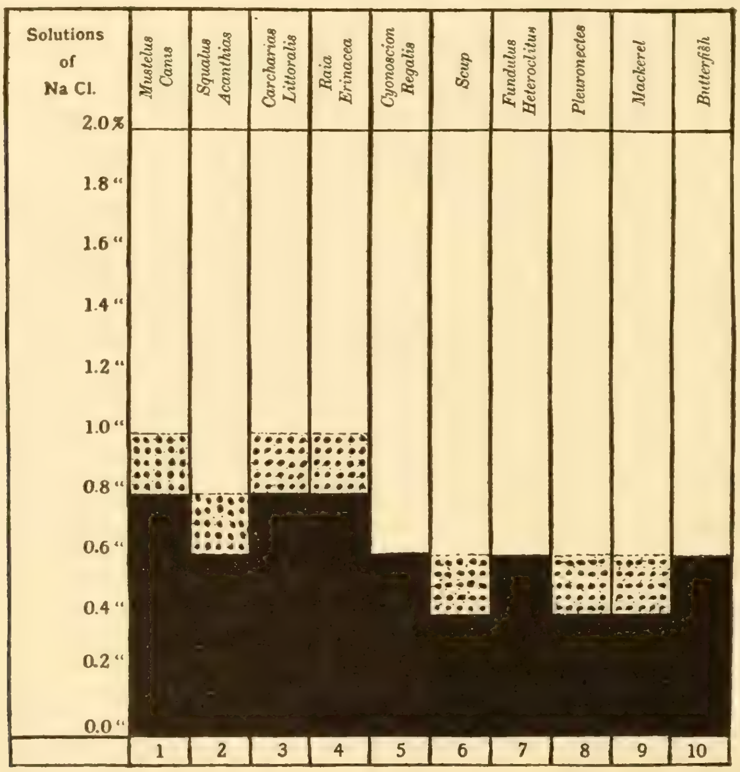

FIG. 9.—*Showing the hemolytic effect of different NaCl solutions on the erythrocytes of four species of elasmobranchs and six species of teleosts. Nos. 1–4 = elasmobranchs; 5–10 = teleosts. Blank spaces, no laking; dotted spaces, faint laking; dark spaces, decided laking.*

found that in the spiny dog-fish the first decided laking occurred in the 0.6 per cent solution of NaCl; in the other three elasmobranchs, in the 0.8 per cent NaCl solutions. In three marine teleosts studied the first decided laking occurred in the 0.6 per cent solutions, while in the other three species decided laking first occurred in the 0.4 per cent NaCl solution. Fig. 9 shows the hæmolytic effect of different NaCl solutions on the corpuscles of four elasmobranchs and six teleosts. Although on the whole, teleost corpuscles are laked by a more dilute solution than is the case with elasmobranch corpuscles, the difference is small as compared with that given by Mosso. The degree of dilution of the solution which first lakes the corpuscles in the two cases is not proportional to the degree of departure from the normal salinity of the blood. Bottazzi and Ducceschi ('96) pointed out that no parallel relation exists between the resistance of the corpuscles and the osmotic pressure of the serum of animals from the different vertebrate phyla. So we may conclude from the above results that whatever be the function of the osmotic pressure of the serum, this is not primarily for the purpose of maintaining the integrity of the corpuscle so far as the retention of its hæmoglobin is concerned. We have seen that the hæmoglobin is retained even though profound changes in the osmotic pressure of the serum take place. Relatively speaking, elasmobranch corpuscles have a greater range in the resistance of their corpuscles than is the case with regard to marine teleosts. They withstand a greater relative reduction of the osmotic pressure of the surrounding medium, *i. e.*, serum, before the hæmoglobin is lost, than is the case of the teleosts. That the death of *Mustelus* is not due to the laking of the blood is seen from the above facts. The swelling of the corpuscles, as shown by hæmatocrit and centrifuge measurement, is probably a matter of greater importance. The imbibition of water may interfere with the gaseous exchanges in the capillaries of the gills. The blood taken in the centrifuge and hæmatocrit measurements described here must have been changed in the gill capillaries and continued to circulate. The gill capillaries do not become completely clogged up with broken down corpuscles as Mosso claimed, as is shown by the fact that the blood used in all these experiments was taken from the caudal artery. The blood of *Mustelus* is first decidedly laked in a 0.8 per cent NaCl solution. The freezing point of such a solution is —0.50° ; but it has already been shown that the freezing point of the blood of *Mustelus* at the time of death in fresh water is about —1.45°, which indicates a dilution insufficient to cause laking. It may be, however, that the stream of blood flowing through the capillaries of the gills is met by an influx of water sufficient to lake some of the corpuscles as they pass by. The experiments demonstrate individual differences in corpuscles, since some are laked and some are not. Whether or not all of the corpuscles are swollen would be difficult or even impossible to determine. The fact that some corpuscles are laked, while the great majority retain their integrity, warrants the conclusion that not all the corpuscles are swollen.

CHANGES IN THE SPECIFIC GRAVITY OF THE BLOOD

The method of Hammerschlag was used in the determination of the specific gravity of the blood of *Mustelus* under normal and experimental conditions. After the normal specific gravity of the blood of each specimen was obtained, the fish was placed in fresh water until near death. Each value of specific gravity given below is the average of four or five determinations.

TABLE XV.—*Showing the specific gravity of the blood of Mustelus in sea-water and after immersion in fresh water*

A—Normal specific gravity of blood	B—Specific gravity of blood in fresh water
No. 1 = 1.0499	1.0483
No. 2 = 1.0448	1.0359
No. 3 = 1.0452	1.0410
Average = 1.0466	1.0417

A fall in the specific gravity of the blood is shown to have taken place after immersion of the fish in fresh water. The blood is therefore more dilute.

CHANGES IN THE PERCENTAGE COMPOSITION OF THE WATER AND THE SOLIDS OF THE BLOOD

It has been shown that profound changes in the molecular concentration of the blood take place when *Mustelus* is immersed in fresh water and concentrated solutions of sea-water. To what are these changes due? Fredericq ('04) concluded that they were caused by absorption of water into the blood. Centrifuge measurements of the blood of *Scyllium* modified by immersion of the animal in diluted sea-water, appeared to show an increase in the relative quantity of plasma. Dakin ('08) held the same view, for he claimed that the modifications in the osmotic pressure of the blood which took place when *Acanthias* had been immersed in fresh water were due to the blood gaining water, and that equilibrium between the internal and the external medium was established by the gain or loss in water being counterbalanced by absorption followed by secretion from the kidneys.

If the modifications in the osmotic pressure of the blood be due merely to the addition or subtraction of water from the gills, then the gills are semi-permeable structures. From what is known of other animals, it is safe to infer that a reasonable excess of water in the blood would be eliminated by the excretory organs. On the other hand, it has already been shown that at the time of death the freezing point of the blood has risen 21.9 per cent. If the blood be merely diluted, the decrease in solids, organic and inorganic, should be proportional to the increase in water. None of the previous investigations contain references to the percentage of water in the blood under the experimental conditions here described. I obtained data with regard to this matter as follows: A certain quantity of blood was drawn from the caudal artery of a dog-fish taken from sea-water. After the artery was closed, the specimen was placed in fresh water for about one hour. The fish was then removed and a second sample of blood was obtained. Both samples were weighed, placed in a hot-air bath at a temperature of about 100° C. and dried to constant weight. The percentage of the dried material was then computed and from this value the percentage of water was obtained. The results are shown in Table XVI.

TABLE XVI.—*Percentage of water and solids of the blood of Mustelus in sea-water and after immersion in fresh water*

A—Normal blood		B—Hypotonic blood	
Water	Solids	Water	Solids
85.39%	14.61%	88.28%	11.72%
87.04	12.96	89.80	10.20
87.06	12.94	88.94	11.06
86.76	13.24	88.81	11.19
89.08	10.92	89.69	10.31
84.38	15.62	87.09	12.91
82.36	17.64	87.23	12.77
82.69	17.31	85.46	14.54
87.60	12.40	88.49	11.51
86.65	13.35	87.36	12.64
87.69	12.31	88.83	11.17
88.18	11.82	89.26	10.74
89.41	10.59	91.01	8.99
Average=86.48%	13.52%	88.48%	11.52%

The average percentage of water in normal blood is found to be 86.48, while that of the blood of the same specimens after immersion in fresh water is 88.48, a gain of 2.0 per cent. Is this gain in water sufficient to account for a rise in the freezing point of the blood of 0.40°? I have found it necessary to dilute sea-water which has the same osmotic pressure as dog-fish blood, 20 per cent with distilled water in order to get a rise of the freezing point equal to that produced in the dog-fishes after immersion in fresh water. It does not seem that in immersion sufficient water has been added to the blood to cause the above lowering of the freezing point. It may, however, be objected that the calculation of the percentage of water in the two cases does not present the matter in its true light. Any addition of water to the blood will separate the cells in the blood to the same degree that it dilutes the soluble substances in the blood. The determination of the dry weight of the blood, therefore, would give a more nearly correct idea of the degree to which the solid substances of the blood are diluted. Normal blood contains 135.2 parts of dried material p. m., while the blood from fishes immersed in fresh water contains 115.2 parts of dried material p. m. That is, the blood after immersion of the animal in fresh water contains 14.8 per cent less dried material than the normal blood. This means first of all less corpuscles; but it also means 14.8 per cent less organic and inorganic substances. It is the inorganic substances in solution which determine in great part the osmotic pressure of the blood. From this standpoint, then, the dilution of the blood has caused a reduction of 14.8 per cent in the osmotic pressure of the blood; but such a dilution is insufficient to account for the rise of the freezing point of the blood actually observed, *i. e.,* 21.9 per cent. It must be concluded, then, that this is not altogether due to mere dilution of the blood by the absorption of water.

CHANGES IN THE NITROGEN CONTENT OF THE BLOOD

A comparison between the organic solids of normal blood and those of the blood after the immersion of the fish in fresh water would also be an index of the dilution of the blood; but the amount of nitrogen present is indicative of the amount of organic material, and therefore I concluded to make determinations of the nitrogen. I wish to thank Dr. W. Denis of the Laboratory of Biological Chemistry of the Harvard Medical School for suggestions as to a modification of the Folin micro-chemical method for the determination of urea which I used in making the nitrogen determinations. After a sample of normal blood was taken, the fish was placed in fresh water until near death. A second sample was then drawn from the caudal artery. Table XVII shows the results of the analysis.

TABLE XVII.—*Nitrogen content of the blood of dog-fishes in sea-water and after immersion in fresh water*

No.	Length in cm.	Weight in gm.	A—Nitrogen in normal blood. Mg. in 1 c. c.	B—Nitrogen in blood after immersion in fresh water. Mg. in 1 c. c.
1.......	72	1077	22.697	18.125
2.......	74	1191	22.775	19.145
3.......	69	1049	23.150	19.875
4.......	74	1389	23.812	20.825
	Average..............		23.109	19.493

The average quantity of nitrogen in the normal blood of *Mustelus* is 23.109 mg. per c. c., while after the immersion of the fish in fresh water it has fallen to 19.493 mg. This means that by immersion the blood has lost 15.6 per cent of its nitrogenous matter. Hæmoglobin is a large nitrogenous component of the blood. It has already been shown that the blood is not laked by the changes produced in its osmotic pressure by the fresh water. The hæmoglobin therefore cannot have left the blood. The greater part of the remaining nitrogenous matter in the blood is present in the proteins of the plasma. It is improbable that they diffuse out through the gills.

On the whole, the conclusion must be drawn that the dilution due to the addition of water to the blood will account for a loss of but 15.6 per cent in the substances in the blood, and also a rise in the freezing point of but 15.6 per cent.

CHANGES IN THE UREA CONTENT OF THE BLOOD

It has been known for some time that urea is present in unusually large quantities in selachian blood. Thus von Schrœder ('90) found that the blood of *Scyllium* contained 2.6 per cent urea, and this was afterward confirmed by other investigators. Urea is usually regarded as a readily diffusible substance. Its gram-molecular solution has about the same osmotic pressure as sea-water, *i. e.,* 22.4 atmospheres. When *Mustelus* is immersed in fresh water, will the urea with its high osmotic pressure diffuse through the extremely thin membranes of the gills and the capillary blood vessels into the fresh water, with a Δ of but 0.025° ? Dr. Denis has kindly made for me the following determinations of the urea in blood which I obtained from four specimens of *Mustelus* under the above experimental conditions. Moreover, the blood was obtained from the same fishes and under the same experimental conditions as described on page —, where my determination of the total nitrogen in the blood is given.

TABLE XVIII.—*Urea content of the blood of Mustelus canis in sea-water and after immersion in fresh water for one hour* (see Table X for sex, length, and weight)

	Urea in normal blood, grams p. m.	Urea in blood after immersion, grams p. m. in fresh water
Fish No. 1..........	15.4	12.6
" " 2..........	15.8	13.2
" " 3..........	15.0	13.2
" " 4..........	15.6	13.2
Average.........	15.45	13.05

This means that the blood lost 15.5 per cent of its urea after immersion in fresh water. The normal blood of *Mustelus* contains 1.55 per cent of urea. This has a freezing point of about —0.45°, and 15.5 per cent of this equals 7.3°. The change in the molecular concentration of the blood is therefore due to other causes than a diminution in the urea. Moreover, the diminution in the urea content is approximately the same as that of the total nitrogen and solids, which, as has been said, indicates in all probability the changes produced by dilution of the blood due to the absorption of water through the gills. These results also show that the maximum change in the osmotic pressure of the blood is due to causes other than its mere dilution.

CHANGES IN THE SALT CONTENT OF THE BLOOD

It has been concluded that sufficient water has not been absorbed to account for the lowering of the osmotic pressure of the blood which my experiments demonstrate to have taken place, when *Mustelus* is immersed in fresh water. Baglioni ('05) and others have shown that the blood of the elasmobranchs that they studied contains about 2 per cent of salts and 2.6 per cent of urea. Although both of these substances contribute to the osmotic pressure of the blood and are readily diffusible, it is generally held that neither diffuses into the external medium when the fish is immersed in fresh water. Yet it has been shown in the preceding experiment that a decrease of 15 per cent in the solids of the blood takes place. Are the salts decreased to a like amount?

In a first series of experiments the blood was weighed, dried to constant weight and ashed, and the ash was analyzed for chlorine by the Volhard method. I wish to thank Dr. George F. White of Clark College and Mr. W. J. Crozier of the College of the City of New York for valuable advice and assistance in the chemical technique here involved. The chlorine in the blood is an index of the salts present. As a check on the method the chlorine content of successive samples of blood from five fishes taken from sea-water was determined. For purposes of comparison the quantity of chlorine present is expressed in grams per 1000 grams of blood. The average amount of chlorine in the first sample of blood taken from each of the five specimens was 6.597 grms. p. m. The average amount of chlorine in the second sample was 6.668 grms. p. m. The difference is within the limits of experimental error. The analysis corroborates the results obtained by measuring the freezing points of successive samples of the blood of the dog-fish taken from sea-water. In a second series of experiments, after a normal sample of blood had been taken from each of five fishes, the fishes were placed in a concentrated solution of sea-water having a Δ of about 3.15° for one hour, at the end of which a second sample of blood was drawn from each specimen. The average amount of chlorine from the normal blood amounted to 6.249 grams per 1000 grams of blood. The average amount of chlorine in the blood after the immersion of the fishes in the concentrated sea-water was 7.522 grams p. m. A gain of 20.4 per cent in chlorine is indicated, which under these conditions probably means a gain of 20.4 per cent in salts. In the third place, an analysis was made of the chlorine content of the normal blood of twenty specimens of *Mustelus canis.* In some cases the blood of two or even three specimens was mixed for a single analysis. Analyses were also made of the blood of twenty fishes after immersion in fresh water. The average quantity of chlorine in the normal blood was 6.098 grams p. m., while the average quantity of chlorine in the blood after immersion of the animal in fresh water for about one hour was 4.638 grams p. m. This means that the blood had lost 23.9 per cent in chlorine; but in this case also the loss in chlorine probably means an equivalent loss in salts. It has thus been shown that on immersion of the animal in a concentrated solution of sea-water the blood gains in chlorine; on immersion in fresh water the blood loses in chlorine.

In order to avoid possible errors due to the volatilization of chlorides through ashing, I decided to make an analysis of the serum of the dog-fish under the above described experimental conditions.

After the blood was drawn in each case, it was first defibrinated and then centrifuged. The supernatant serum was drawn off with a volumetric pipette. In some cases it was necessary to use the mixed sera of two specimens for an analysis. Five c. c. of serum was placed in a volumetric flask of the capacity of 100 c. c. About three c. c. of pure acid was added. The flask was half filled with distilled water and the contents were heated to boiling for about two minutes, after which the liquid was allowed to cool, the flask was filled to the mark with distilled water and the contents were shaken. The whole was then filtered and 50 c. c. of the filtrate was used for an analysis of its chlorine by the Volhard method. The amount of chlorine thus determined was multiplied by two, giving the amount present in the original 5 c. c. of serum, and from this the amount present in 1000 parts of serum was easily calculated. Table XIX shows the results of the analysis of the chloride in five samples of serum taken from seven fishes immersed in sea-water and in six samples of serum taken from six fishes that had been transferred from sea-water to fresh water for somewhat over an hour.

TABLE XIX.—*Chlorine content of the blood serum of dog-fishes in sea-water and after immersion in fresh water*

Number	Chlorine in serum from fishes taken from sea-water, in grams p. m.	Number	Chlorine in serum from fishes after immersion in fresh water, in grams p. m.
1	8.778	1	5.824
2	8.400	2	6.755
3	8.246	3	6.181
4	8.715	4	6.608
5	9.079	5	6.734
		6	6.433
Average	8.643	Average	6.422

The average in the case of the first group is 8.643 p. m., while that for the second group is 6.422 p. m., a difference of 25.7 per cent, representing the loss of chlorine resulting from the immersion.

The greater percentage of Cl in the serum than in the blood is due to the fact that practically all the chlorides of the blood are dissolved in the serum. The significant feature of the two groups of analyses is that the percentage loss in chlorine is approximately the same in the two cases. The results warrant the conclusion that after immersion in fresh water for about an hour, *i. e.*, until near death, the blood contains about 25 per cent less chlorine in solution than is the case with normal blood. This means that the salt content of the blood is less than the urea and other nitrogenous substances. If there had been no loss of salts by diffusion, then there should have been a decrease of but 15 per cent in the salts at the end of the period of immersion in fresh water. We are driven logically to the conclusion that the excessive diminution in the salts of the blood takes place by diffusion through the gills and that the gill membranes become permeable to them.

Regulation of the Osmotic Pressure of the Blood of *Mustelus*

A constant osmotic pressure of the blood is regarded as necessary for the normal activities of cells and tissues of the higher forms. The kidneys are recognized as being primarily concerned in maintaining this constant pressure. Their activity in this connection will be considered later. In addition to the kidneys, it has been pointed out by Buglia ('09) that the tissues take part in this regulation. Buglia found that injections of hypotonic salt solutions into the circulation of a dog produced little effect on the molecular concentration of the blood. He concluded that the excessive water disappeared with astonishing rapidity from the blood plasma by entering the cells or tissues. In this way the normal osmotic pressure of the blood was maintained. Japelli ('06) found after intravenous injections of hypotonic solutions of sodium chloride into the circulation of the dog, that the muscles took up water from the blood, thus exerting a regulative action on the osmotic pressure of the blood. When *Mustelus* is immersed in fresh water, its tissues are bathed by diluted blood. Is there any evidence of an attempt on the part of the tissues to maintain the normal osmotic pressure of the blood by taking up water from the hypotonic blood which bathes them? Various organs, namely, the brain, heart, kidney, spleen and muscle, were removed from several dog-fishes which had been in sea-water. The same organs were removed from other fishes that had been immersed in fresh water until near death. Each organ was placed on filter paper, the heart and brain being cut open, and the other organs being cut into small pieces. All free fluids were removed with filter paper. Each organ was then weighed and put at first into a hot-air bath at 100° C. for a time and then into a dessicator over sulphuric acid. A partial vacuum was made by withdrawing air by means of a filter pump. When the organs were dried to constant weight, the percentage of water in each case was calculated. The results of this experiment are shown in Table XX.

TABLE XX.—*Percentage of water in various organs of the dog-fish when the animals were taken from sea-water and after they had been immersed in fresh water for about two hours*

Brain		Heart		Kidney		Spleen		Muscle	
Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
79.2	81.8	81.2	83.6	76.6	82.1	76.4	81.0	74.4	81.5
82.9	82.8	84.2	85.3	81.5	82.6	77.2	31.6	80.4	77.8
81.9	83.0	81.0	84.7	77.9	81.6	77.9	77.9	78.7	78.9
77.0	82.0	80.0	86.0	79.8	82.0	79.4	77.8	77.6	83.0
78.9	83.3	80.6	86.8	97.3	79.6	78.6	82.2	77.5	83.9
81.7	87.6	80.6	85.7	78.3	84.0	78.3	84.1	79.7	82.5
79.1	87.6	79.3	87.4	79.6	86.4	78.1	84.3	80.8	84.7
82.3	86.4	80.2	86.2	79.5	86.2	77.6	81.9	79.2	85.1
80.2	88.2	81.0	97.0	78.9	87.4	77.6	80.6	79.1	77.6
79.0	88.3	81.7	89.1	79.7	85.4	76.7	80.6	78.2	82.7
78.7	81.5	80.6	81.7	78.8	80.8	78.5	71.9	77.2	80.2
79.7	80.8	82.0	82.1	78.1	80.8	78.2	78.7	81.6	80.5
77.9	82.1	80.6	81.3	78.3	79.7	78.6	78.6	78.7	82.9
79.7	82.3	80.3	82.6	78.2	82.8	77.1	75.6	85.5	82.0
78.3	81.6	81.1	83.5	82.1	81.5	78.3	80.7	78.9	85.3
75.6	81.5	78.9	83.5	78.3	80.7	77 0	80.5	80 2	80.5
	81.5	80.3	84.2	78.5	81.3	78.5	80.1	83.5	79.1
	81.3	82.6	81.6	79.1	80.4	77.3	79.4	77.8	....
	....	74.3	83.7	75.3	82.1	....	79.2	....	....
Averages, 79.5	83.6	80.5	84.5	79.3	82.5	77.8	79.8	79.4	81.7

An examination of the table shows that the organs of the animals that had been immersed in fresh water contain more water than those of normal animals; the various tissues show the following increases: Brain, 4.1 per cent; heart, 4.0 per cent; kidney, 3.2 per cent; spleen, 2.0 per cent; muscle, 2.3 per cent. The average percentage of water in normal tissues was 79.3 per cent, while in the fresh water specimens it was 82.4 per cent, an average gain of 3.1 per cent. It thus seems certain that the tissues take up a certain amount of water from the blood, when this is made hypotonic by the immersion of the fish in fresh water. From this it must be concluded that the tissues of an animal constitute a mechanism for the regulation of the osmotic pressure of the blood.

It was stated above (p. 51) that the kidneys are concerned in the regulation of the osmotic pressure of the blood of higher forms. Mammals after drinking a great amount of water secrete a greater amount of urine than usual. This urine is also more dilute than normal urine. Whereas in man urine usually has a specific gravity of 1.020, the dilute urine may have a specific gravity of 1.002 (Hammarsten). Overton found that water absorbed through the skin of the frog is excreted by the kidneys.

Fischer ('10) found that if a ligature was tied about a frog's leg and the animal was put into fresh water the leg became greatly swollen because of the absorption of water. The circulation of the blood and lymph being stopped by the ligature, the kidneys could not pass off the excess of water. Will the kidneys of *Mustelus* act in the presence of the diluted blood in such a manner as to conserve the normal osmotic pressure of the blood?

Observations were made by Dr. W. Denis and the author on the quantitative secretion of the urine of *Mustelus*. The method of collection has been described by Denis ('12). The average secretion of urine per 24-hour period was 21.6 c. c. The urine does not appear to be eliminated constantly but periodically, as in the case of the higher forms. Since *Mustelus* dies in about an hour after immersion in fresh water, no attempt was made to collect the urine during such a short period. The effect of four other solutions, however, the osmotic effects of which have already been shown, were tried: namely, sea-water; concentrated sea-water having a Δ of 2.60°; three-fourths sea-water plus one-fourth fresh water; and one-half fresh water plus one-half sea-water. For the first few hours after immersion the average secretion per hour for four specimens in sea-water was 0.4 c. c. urine; in the concentrated solution of sea-water, the average secretion of two fishes was 0.2 c. c. urine; in the solution of three-fourths sea-water plus one-fourth fresh water, the average secretion of two fishes was 1.2 c. c. urine; and in the solution of one-half sea-water plus one-half fresh water, the average secretion of five fishes was 1.4 c. c. urine. The results show that, in the concentrated solution of sea-water, less urine, and, in the dilute solutions, more urine is secreted than in normal sea-water. There is no doubt then that the immersion of the fish in modified solutions of sea-water with the resulting changes in the molecular concentration of the blood, causes an immediate reaction on the part of the kidneys.

The nature of the urine thus secreted as compared with normal urine is shown by the results of the following experiments: The Δ's of the urine collected from three dog-fishes immersed in sea-water were respectively 1.69°, 1.70° and 1.77°. The average of these values is 1.72°. These results indicate that it may be hypotonic and not isotonic with the blood. Bottazzi ('06) stated that elasmobranch urine is isotonic with the blood, although some of the results given by him indicate that it is hypotonic. The Δ of the urine collected from a dog-fish immersed in a solution of one-half sea-water plus one-half fresh water for about four hours was 1.61°. Furthermore, the specific gravity of two samples of normal urine was found to be 1.034 and 1.037, while that of two samples of urine collected after immersion of two fishes in one-half sea-water plus one-half fresh water was found to be respectively 1.030 and 1.026. The specific gravity determinations were made on fresh urine. One sample was large enough for the use of the hydrometer. The other determinations were made with the pycnometer. Denis ('12) records the normal urine of one *Mustelus canis* as 1.032.

Finally, the average amount of chlorine in two samples of normal urine was 9.1812 gms. Cl per 1000 c. c. urine, whereas the chlorine in the urine of two other fishes immersed in a solution of one-half sea-water plus one-half fresh water for about four hours amounted to 6.9517 gms. Cl per 1000 c. c.

It must be concluded, therefore, that the urine collected from fishes immersed in diluted sea-water is more dilute than normal urine. What is the concentration of the blood under these experimental conditions? Are the activities of the kidneys such as to conserve in any way the osmotic pressure of the blood? In the specimen whose urine had a Δ of 1.61° after about four hours' immersion in one-half sea-water plus one-half fresh water, the Δ of the blood was 1.64°. The blood is slightly more concentrated than the urine; but it has already been shown that there is a great reduction in salts in the urine of the fish immersed in fresh water. This leads to the conclusion that the salts are not being excreted, but are being held back by the excretory organ. The kidneys are acting to maintain the osmotic pressure of the blood by the excretion of water. The problem is complicated by the fact that constantly water is coming into and salts are leaving the blood through the gills.

Presence of Salts in the External Medium after the Immersion of Fishes in Distilled Water

If salts diffuse from the blood out through the gills, an analysis of the diluted sea-water in which *Mustelus* is immersed should reveal the presence of these salts. To test this I made the following experiment:

A male dog-fish 60 cm. long was pithed and a bolus of oiled cotton was placed at the entrance of the stomach to prevent regurgitation of the stomach contents. The fish was then immersed in sea-water. This was gradually changed to fresh water in about five minutes, when the fish was removed, thoroughly washed in fresh water and placed in a jar containing two liters of distilled water. No urine was allowed to enter the jar. Air was bubbled into this water during the course of the experiment. The fish was near death when taken out of the jar forty-five minutes later. The chlorine in one-half of this water was then determined in the following manner: The sample was boiled down to 200 c. c. and filtered; 20 c. c. of the filtrate was analyzed for chlorides by the Volhard method. This was repeated five times. The average results equaled .0253 parts chlorine per 100. This is more than twenty times as much Cl as is present in the fresh water of Woods Hole. In a second experiment carried on in the same way, two fishes were immersed in four liters of fresh water. After death, the water was evaporated down to the volume of one liter and aliquot portions of this showed the presence of .68 gms. Cl in the water, or .01708 gms. chlorine per 100. This value is nearly twenty times the amount of chlorine found in the fresh water. In these experiments there were only two possible sources of the chlorides. One was the skin; but in view of the thorough washing of the external surface in fresh water this does not appear to me a probable source. The other was the gill membranes. Diffusion through these structures seems to afford the logical explanation of the presence of the salts in the water of immersion.

Effects of Immersion in Fresh Water on Blood Pressure, Respiration and Heart Beat

The effects of immersion on blood pressure are not so marked as on respiration and heart beat. In general, however, it can be said that from the time the fresh water is turned into the tank the blood pressure falls. The variations in blood pressure were recorded in the following manner: After a fish had been pithed, the tail was removed and a canula filled with a solution of sodium carbonate was inserted in the caudal artery. The fish was then placed in a tank of running sea-water. The canula was then connected with a recording tambour also filled with the sodium carbonate solution. The lever of the tambour recorded the blood pressure and the heart beats on a slowly moving drum. After a normal record had been obtained the fresh water was turned on. The fall in blood pressure varies in individuals, and appears to be correlated with respiratory rate and heart frequency. The blood pressure rises at times, but soon falls to its former level. This momentary variation is also connected with the variations in the heart beat. In three experiments at the time of death in fresh water, *i. e.,* when respiration had permanently ceased, there was a fall in blood pressure of about 30 per cent from the normal. Fig. 10 shows the change in blood pressure of *Mustelus* from the time of immersion in fresh water at 9.50 A. M. until its death at 11.15 A. M.

Immersion in fresh water results in the gradual cessation of respiration. For example, in one case there were 59 respirations per minute at the time when the sea-water was changed to fresh water; there were 61, four minutes after; 60, eight minutes after; 56, twenty-two minutes after; 46, thirty-one minutes after; 33, thirty-seven minutes after; 31, forty-two minutes after; 43 very feeble respirations, forty-eight minutes after; 14, feeble, at fifty-five minutes; 8, very feeble, at sixty-seven minutes; after which the experiment stopped. In some cases, the diminution in respiratory rate toward death was still more marked. Moreover, the respiratory movements gradually became less forcible. Toward death, they were very weak and consisted of but gentle movements of the gill covers, to the eye ineffective as compared with normal respirations. The respiratory movements at times ceased for a period altogether and then suddenly broke forth with rapidity and force, soon fading, however, to

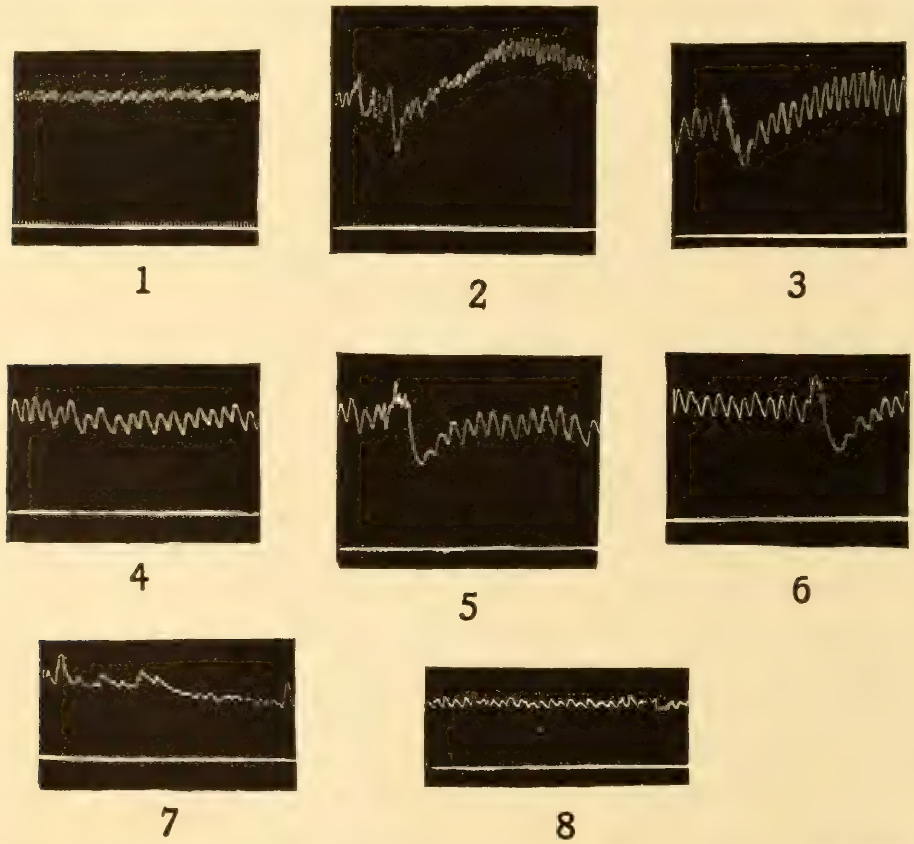

FIG. 10.—*Showing changes in blood pressure of Mustelus canis due to immersion in fresh water*

complete cessation. Respiration ceases before the heart stops. Now and then in normal respiration slightly convulsive movements of the gill apparatus is observable. These have been noted by Hyde ('04-'08) in the case of the skate. She drew the conclusion that these movements constitute an attempt on the part of the fish to force a sudden strong current of water through the gill apertures, the effect of which is to clean the gill membranes of any foreign matter collected from the sea-water during the course of normal respirations. After the fresh water was turned on, one of the commonly observable effects consisted of violent respiratory spasms accompanied by movements of the whole head. These spasms increased in intensity and frequency until nearly an hour after immersion, and then gradually and irregularly declined in number and strength. These respiratory movements are possibly modifications of increased intensity of the normal gill-cleaning movements mentioned above. It is also possible that both have fundamentally the same cause but that the stimulus is more intense when the fish is immersed in fresh water. Foreign ma-

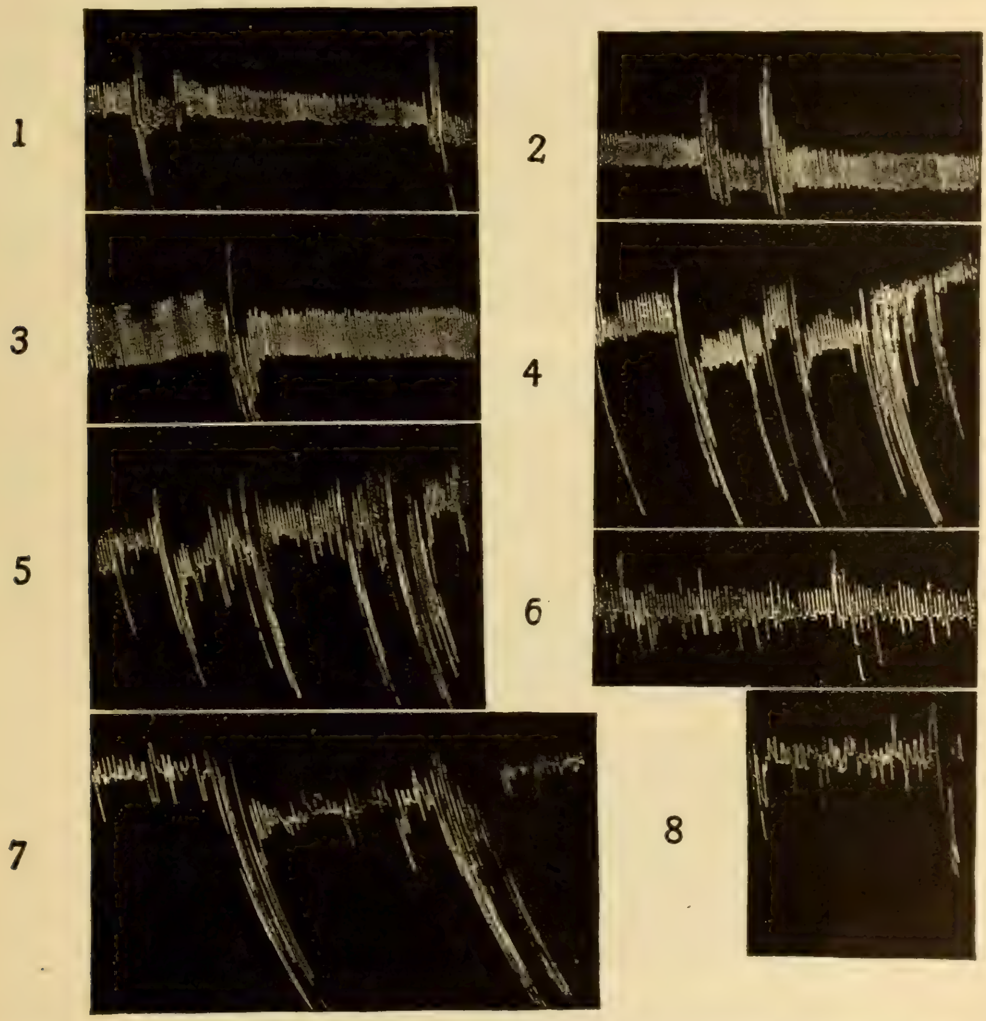

FIG. 11.—*Showing the change in the character of the respirations during an hour after immersion of Mustelus in fresh water. Irregularities represent spasmodic respiratory movements.*

terial on the surfaces of the gill membranes prevents the normal functioning of these structures and tends toward asphyxiation. The changes in the gill membranes brought about by immersion of the fish in fresh water are accompanied by the same convulsive gill movements.

There is considerable variation in the respiratory modifications in individuals, but the above mentioned features were observable in most fishes studied. At times, the respiratory rate and heart frequency are equal; but they appear to be little correlated. After immersion in fresh water, there is rarely any sign of relation between the two rates. Fig. 11 shows the change in the character of the respirations due to the immersion of *Mustelus* in fresh water.

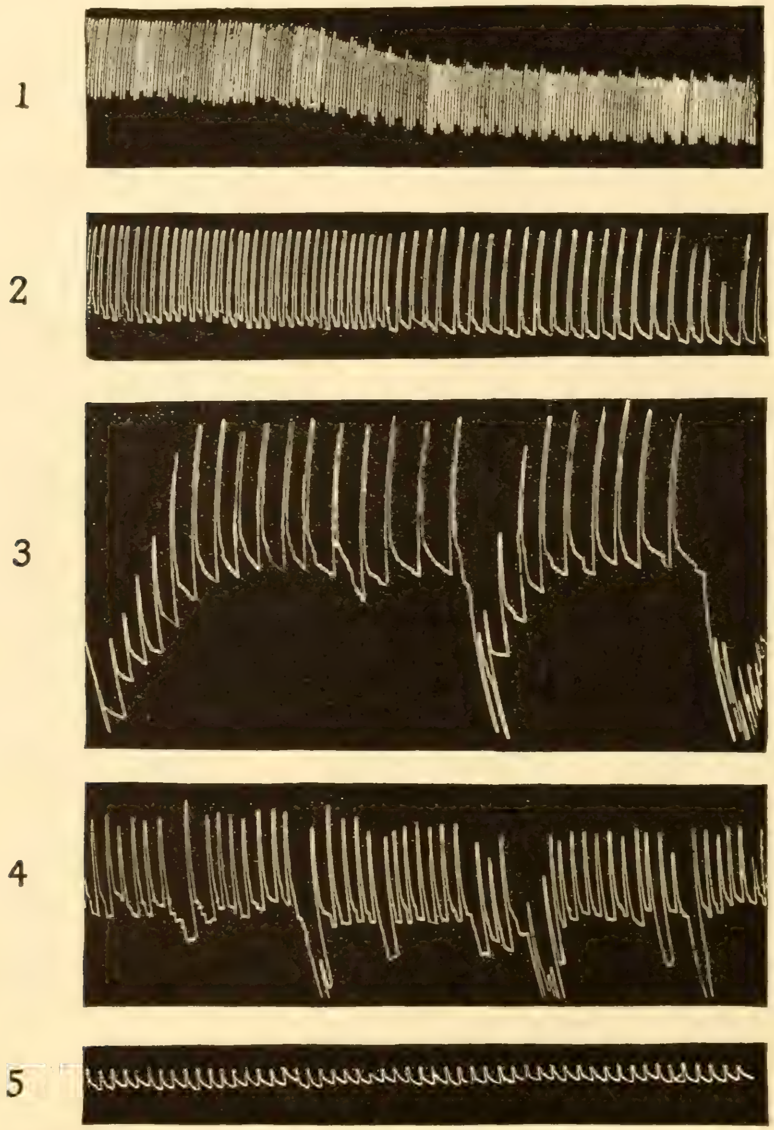

FIG. 12.—*Showing changes in heart beat of Mustelus due to immersion of fish in fresh water. Irregularities represent spasmodic cardiac movements*

The effect on the heart beat of the immersion of *Mustelus* in fresh water was studied directly in the following experiment, of which Fig. 12 is a record: A female *Mustelus canis* 79 cm. long, 1247 gms. in weight, was pithed and an opening about 1 cm. square was made in the pectoral arch over the pericardial cavity. A fine hook was attached to the tip of the ventricle and connected by a thread to a lever recording on a slowly moving drum. With its dorsal surface downward the fish rested on an inclined support in a tank of sea-water so that the head and gills were under water. No sea-water entered the pericardial cavity. After the normal heart beat had been recorded for a few minutes, a stream of fresh water was turned into the tank, and a record was made of the changes in the heart beat for 80 minutes. During the period that the fish was immersed in sea-water, the heart was beating at the rate of 50 per minute. The rate changed to 59 per minute during the second minute after the fresh water had been turned on, and then gradually fell as follows: 6th minute, 45 beats per minute; 12th minute, 28 beats; 16th minute, 13 beats; 18th minute, 11 beats, 22nd minute, 9 beats; 30th minute, 10 beats; 35th minute, 6 beats; 44th minute, 14 beats; 51st minute, 12 beats; 58th minute, 13 beats; 70th minute, 15 beats; 75th minute, 14 beats; 80th minute, 12 beats. Accompanying the early diminution in heart rate, there was an increased amplitude of contraction. In fact, the amplitude of the beat varied for a time inversely with the rate. The increased amplitude and slower rate began to be marked about the 14th minute after the fresh water was turned on, coinciding somewhat with the time at which the water was entirely fresh, being most marked between the 30th and 40th minutes. A diminishing respiratory rate accompanied this increased amplitude of contraction. The forcible and slow heart beat gradually failed after respiration ceased. Soon after respiration ceased, the heart beat showed great irregularity in the time taken by each contraction. At the end of an hour, the amplitude of contraction was about equal to that of the normal heart beat but the rate was only about one-fourth as great. After this, the extent of the contraction diminished gradually, although by stimulating the heart mechanically it increased for a time. About 70-80 minutes after immersion in fresh water and about twenty minutes after respiration ceased, the heart beat, although slow and regular, was very weak and was probably not effective enough to drive the blood through the gill capillaries with sufficient rapidity to maintain life. This agrees in the main with Mosso's ('90) observation.

Another related feature accompanying the change in cardiac activity were the respiratory convulsions similar to those mentioned on page 57. This is strongly suggestive of an associated action of the bulbar cardiac and respiratory mechanisms which exists in the mammal. The gill covers became greatly contracted and simultaneously the heart was slowed and greatly dilated. The inhibition of the heart in diastole and the character of the recovery as shown in Fig. 12 suggests that the cardiac spasm is possibly an instance of reflex inhibition of the heart beat due to the cardiac-inhibitory center being stimulated by impulses from sensory nerves; but the heart gradually recovered the force and rate it had prior to the convulsive movement, and the respiratory spasm ceased.

During the twenty minutes after immersion, there occurred about ten very marked respiratory spasms with their accompanying effects on the heart. Twenty or more took place during the second twenty minute period. After this they diminished in number and force, ceasing almost entirely about the 70th minute. Some respiratory convulsions took place

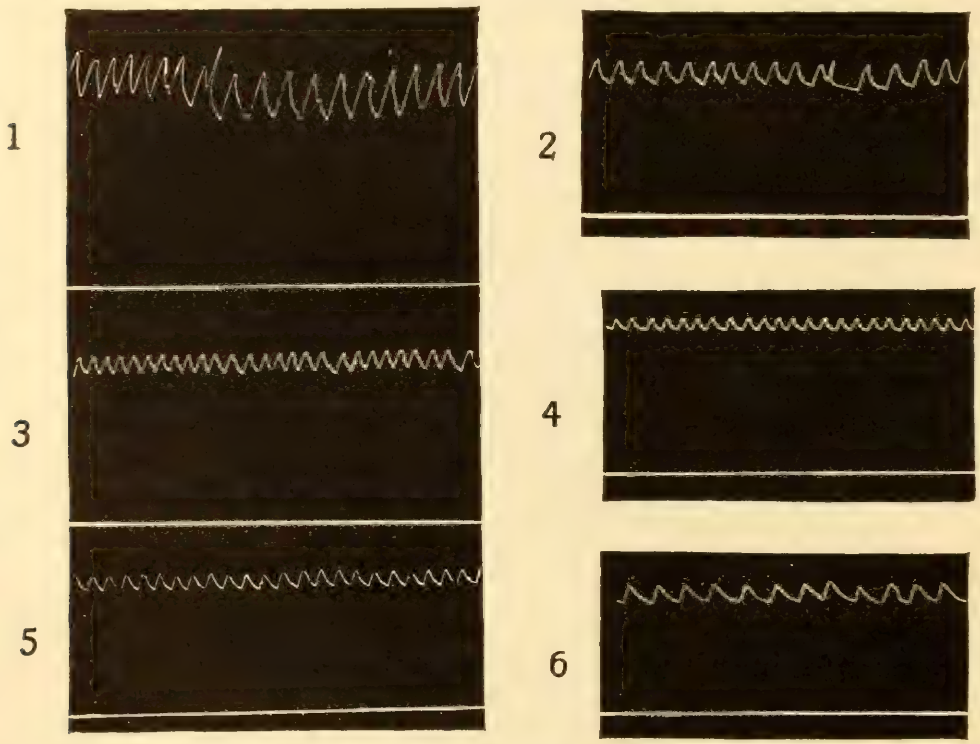

FIG. 13.—*Showing changes in blood pressure and heart beat of Squalus due to transference from harbor water to fresh water from 11.06 A. M. to 3.56 P. M.*

after regular respirations had ceased. Fig. 12 shows the changes in the character of the heart beat of this specimen.

The case with *Squalus acanthias* studied at the New York Aquarium during the early winter, December, differs from that of *Mustelus.* The water in which these fishes had been kept had a temperature of about 12° C. Moreover, the fishes, as has already been described (p. 32), had been living in a diluted sea-water for some time. The rate of the heart and of the respiration was much lower than in the case of *Mustelus* in summer. Moreover, it was observed that the fishes lived longer after the fresh water was turned on than was the case with *Mustelus.* One specimen was under observation for five and one-half hours, during which a record was kept of its blood pressure. This fell 30 per cent from its value at the beginning of the experiment. The fall was gradual. The heart was beating at the rate of 16 per minute at the beginning of the experiment and 8 per minute at the end. Respirations were at the rate of 14 per minute at the beginning and ceased about four hours after fresh water had been turned on. Fig. 13 shows the character of the changes in blood pressure and heart beat in this specimen. The absence of the spasmodic respiratory movements is apparent. Other spiny dog-fishes at the New York Aquarium did not withstand the immersion for so long a time. But in every case with *Squalus* the changes in blood pressure, respiratory rate and heart beat took place much more slowly than was the case with *Mustelus*. There are two factors that may have a causal connection with this difference. In the first place, because of its immersion in diluted sea-water during its stay in the aquarium, *Squalus* may have acquired a certain kind of immunity to the freshened water, so that a transition to wholly fresh water would not have such a quickly fatal effect as in the case of *Mustelus*. That the factor is not altogether the change in the osmotic pressure of the blood is suggested by the fact that after about an hour's immersion in fresh water the Δ of the blood of a number of spiny dog-fishes, as has been shown on page 33, was about the same as that of *Mustelus*, although it must be confessed not quite so high. In the second place, the temperature of the water in which the spiny dog-fishes had been kept as well as that of the fresh water in which the fishes were immersed in the experiment was low, the latter being 12° C. Metabolism was probably at a low ebb, and therefore chemical and physical changes would take place more slowly.

In publishing blood pressure tracings from the Chinook salmon, Greene ('05) states that certain waves, which are shown, are due to the rhythmical effect of respirations on the blood pressure which also records heart beats. A series of waves similar to those published by Greene are now and then found in the normal blood pressure tracing from *Mustelus* as shown by Fig. 10-1. In this case, it is certain that the waves are not all synchronous with the respirations, nor have the respirations anything to do with them. On the contrary, these are evidently Traube-Hering waves and probably due to rhythmical variations in the tone of the vaso-motor center. Almost as many respiratory movements take place during each of these rhythmical periods as there are heart beats recorded. It may be that the waves in this case are due to the destruction of the spinal cord. All indications of them cease when the animal is placed in fresh water.

That the heart action is not altogether dependent upon respiratory activity is shown by the fact that the heart continues to beat long after respiration has ceased. The respiratory rate may suddenly increase temporarily, while the heart rate is steadily declining. On the other hand, the heart rate may become more frequent while the respiratory rate is declining.

Parker ('10) stated "that the rate of gill movement in the dog-fish depends upon the momentary state of movement of the animal. When resting, they vary from 35 to 40 movements per minute. When swimming slowly, they respire 50 to 55 times per minute. In vigorous swimming, the rate is doubtless still more rapid." The accompanying figure, Fig. 14, is a record of the respiratory and cardiac activity taken simultaneously, and shows that while the respiration rate is 52 per minute the heart rate is but 40 per minute. At times, the two rates may be equal; but this is rather the exception, so far as my observation goes. The two seem to be independent.

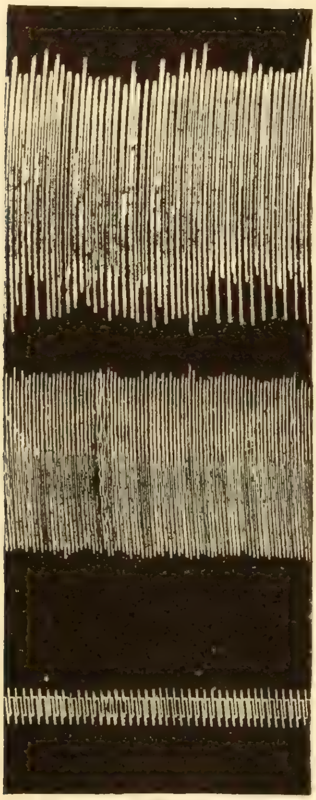

FIG. 14.—*Comparative rate of respiration and heart beat in Mustelus in sea-water. Upper tracing, heart beat, 40 per minute; below this, respiratory, rate, 52 per minute.*

We may conclude that the respiratory convulsions described above do not produce cardiac spasms as shown in Fig. 12, but, on the contrary, the two processes occur simultaneously and both have the same cause.

We know that the density of the water is changing constantly, but these spasmodic movements occur long after the water becomes fresh. The movements cannot be due to the stimulus of changing external density. We know, too, that the osmotic pressure of the blood is changing constantly; indeed, the change continues long after the water has become fresh and continues to change up until the death of the animal. Owing to swelling corpuscles, dilution of the blood and alterations in the gill membranes, it is probable that the blood fails to get oxygenated and that its CO_2 increases in quantity. In fact, the blood drawn from the caudal artery at the end of the experiment has a dark appearance, brightening upon exposure to the air. If thus the blood becomes profoundly venous, laden with CO_2 it would flow through the respiratory center and cause spasmodic contractions of the respiratory muscles.

Discussion

The changes in the osmotic pressure of the blood of *Mustelus canis* after immersion in diluted and concentrated solutions of sea-water have been shown in the preceding pages. It has been shown that this dog-fish differs from the marine invertebrates in that the osmotic pressure of its blood does not become equal to that of the surrounding medium, when this differs in its concentration from the sea-water. Moreover, when a considerable change has been produced in the osmotic pressure of the blood of *Mustelus* by immersion in a modified solution of sea-water, the normal osmotic pressure of the blood is not regained on the return to sea-water. In this respect, also, the elasmobranch differs from the marine invertebrate.

The elasmobranchs differ also from the marine teleosts, the osmotic pressure of whose blood is between one-third and one-half that of the external medium, and whose blood maintains a constant osmotic pressure despite marked changes in the osmotic pressure of the external medium. The elasmobranchs cannot in truth be termed either poikilosmotic or homoiosmotic animals. It has been shown that the freezing point of the blood rises about 0.40° C. on immersion in fresh water until near death, and 0.18° C. on immersion in sea-water diluted with an equal volume of fresh water, having a freezing point of —1.00°. In both cases the change in the osmotic pressure of the blood is about one-fourth of the change in the external medium. In concentrated sea-water having a freezing point of about —2.60°, or about 0.80° below that of sea-water, the osmotic pressure of the blood increases about one-fourth as much as the change in the external medium. In these three cases, the change in the osmotic pressure of the blood though not equal to the change in the osmotic pressure of the external medium, yet bears a rather constant ratio to the external change.

This appears to be the index of a certain degree of independence on the part of the animal of the osmotic pressure of the external medium. From this point of view, it would be correct to consider the elasmobranchs as occupying a position midway between the marine teleosts and the marine invertebrates as to the relations of the osmotic pressure of the internal fluids of the body to the external fluids in which these forms live.

The problem, however, calls for further analysis. In the first place, it is necessary to know what parts of the elasmobranch body are concerned in the osmotic changes which cause the death of the animal in the modified external medium. Evidence has been presented showing that there are two gateways between the internal media and the external medium, namely, the gill membranes and the kidneys. After immersion of *Mustelus* in diluted sea-water, of course all movement of liquids in the case of the kidneys must be from within outward; in the case of the gill membranes the movement may be in both directions.

Information has been gathered from the experiments as to the condition of the blood due to immersion of the fish in the modified sea-water. In fresh water, the specific gravity of the blood is less than normal; the solids are 14.8 per cent less; the nitrogenous substances 15.6 per cent less; the urea content has decreased 15.5 per cent; the chlorine content is 25.7 per cent less and the osmotic pressure has fallen 22 per cent. When hypertonic saline solutions are introduced into the blood system of an animal, one of the first reactions is the withdrawal of water from the tissues into the blood; but the present condition is the reverse. The blood is deficient in salts. The tendency of the tissues will be to absorb water from the blood. Evidence of this reaction has been presented on page 52. But sufficient water cannot be taken into the tissues to counteract the constant inflowing of water from the exterior. Even before the tissues have begun to take up water, it is probable that the kidneys, stimulated by the modified diluted blood, react in such a way as to cause an increased secretion of water. The urine formed under these conditions has a lower specific gravity, lower osmotic pressure and lower chlorine content than the normal urine. Moreover, the quantity of urine secreted is in excess of the normal quantity. It is possible that the excessive secretion of urine is due in the last analysis to an increased amount of water in the blood flowing through the capillaries of the kidney. If any considerable quantity of water has entered, there must have been a readjustment of the caliber of the blood vessels, since no marked increase in blood pressure can be detected. Baglioni called attention to the fact that when almost all the blood was withdrawn from an elasmobranch *Scyllium,* in a short time the blood contained almost the normal percentage of urea, although it had a lower osmotic pressure than normally. Moreover, he found that a starving *Scyllium* also exhibits a tendency to retain its urea. It appears therefore that the cells of the kidney are capable of retaining to a certain degree the urea as well as the salts. It appears probable that the dog-fish possesses a mechanism for the regulation of the osmotic pressure of its blood which is efficacious in the case of slightly diluted external media.

I have shown, however, that at the time of death of *Mustelus* in fresh water there is a deficiency of 15.5 per cent in urea and other nitrogenous substances of the blood which I claim to be largely due to dilution of the blood. The chlorine of the blood has decreased nearly 26 per cent. This probably means an excessive loss in salts, which would account for the greater decrease in the osmotic pressure of the blood.

We may next consider the contribution of the salts and urea to the osmotic pressure of the blood. The usual impression one gets from a perusal of the literature is that the osmotic pressure of the blood is due almost wholly to the presence of crystalloids, *i. e.,* chlorides and urea. By the method of ashing, it is probable that some small part of the chlorine is lost by volatilization. In the method used above for the determination of the chlorine in serum, it is possible that a certain amount of salts was retained by the diffusates. Nevertheless, every care was taken to prevent error in the analyses. The determination of the urea was likewise as carefully made. Dakin ('08) found that the blood of *Acanthias vulgaris,* the freezing point of which is almost identical with that of *Mustelus,* contained 0.88 per cent chlorine. The serum of *Mustelus* blood contains, according to my analyses, 0.86 per cent chlorine. Expressed in terms of sodium chloride, this means that there was present 1.424 per cent NaCl. The urea formed 1.55 per cent of the blood (*i. e.,* corpuscles and plasma). This is somewhat greater than the percentage of salts. In the analyses given by other investigators, a greater amount of urea than salts was also found. Moreover, when one takes into consideration the differences in the osmotic pressure of the sea-water at the stations where other investigations have been made, knowing selachian blood to be approximately isotonic with its sea-water medium, one finds that the change in the percentage composition of the salts and the urea is proportional to the modification of the osmotic pressure of the external medium.

By analysis, it was found that 1.55 per cent of the blood, plasma and corpuscles is urea. This means that the urea constitutes 1.94 per cent of the serum, which is equal to a 0.32 gram molecular solution. Since the freezing point of a gram molecular solution is —1.84° (Nernst, '09) a 0.32 solution would have a freezing point of about —0.59°. This amount represents the lowering of the freezing point of the blood due to urea. The salts present in the blood are, however, equivalent to a 0.24 gram molecular solution of sodium chloride. This, allowing for dissociation, has a freezing point of —0.85° [3]. This represents the lowering of the freezing point due to the inorganic salts of the blood. The sum of 0.59° and 0.85°, or 1.44°, represents the lowering of the freezing point of the blood due to both its urea and inorganic salts. The freezing point of the blood is, however, —1.87°. There is thus left 0.43° to be ac-

[3] As computed from Landolt and Börnstein's Tabellen '05.

counted for. Macallum ('10) found that the urea and salts of the serum of *Acanthias vulgaris* would not account for its freezing point. He concluded that the difference between the freezing point of serum and that produced by the combined salts and urea was due to the other organic solutes. These were found to be ammonia salts, which were present in amounts sufficient to account for the additional depression of the freezing point. We may infer that ammonia salts are present in the blood of *Mustelus*. By these and other organic solutes, such as sugar, the freezing point of the blood is brought to —1.87°. The rôle of these substances, which are also crystalloids, has been too much neglected.

Mines ('12) described the effects of electrolytes on the elasmobranch heart. The work was done at the laboratory of the Marine Biological Laboratory at Plymouth, England. The normal freezing point of the forms used was probably similar to that of *Mustelus*, namely, —1.87°. Records were made showing the effects of solutions perfusing the heart. The fluid was adapted from one used successfully by Knowlton, whose results have not as yet been published. From the formula given by him, I conclude that Mines's solution must have had a freezing point less than —1.52°. In other words, the solution was hypotonic to the blood which normally bathed the heart. It contained about the same percentage composition of metallic elements (sodium, potassium, calcium and magnesium) as determined by Macallum, and urea and chlorides as determined by myself. Since each of the kations has been shown by Mines to have a specific effect on the heart action, his perfusion solution probably contained the optimum amount of these substances. Baglioni's experiments on the maintenance of the heart beat of elasmobranchs were carried on at Naples, where the mean freezing point of elasmobranch blood is —2.29°. The author used two solutions, one being a 3.5 per cent solution of sodium chloride, which is isotonic with the blood. The other solution consisted of 2 per cent sodium chloride + 2.2 per cent urea plus a trace of calcium chloride. The computed freezing point of such a solution is about —2.00°. The freezing point of a solution of 2 per cent urea + 2 per cent NaCl obtained by means of the Beckmann apparatus is about 1.80°. Hence the solution with which Baglioni obtained his results was in all probability somewhat hypotonic to the blood of the elasmobranchs he used.

If we subtract from the normal freezing point of the blood, the freezing point due to the salts, *i. e.*, about —0.85°, there is a remainder of —1.02° which is caused by urea and other substances in solution. It has been noted that when the fish is immersed in fresh water, the nitrogenous substances are decreased at death by 15.5 per cent. The freezing point of the blood should undergo a similar reduction of 15.5 per cent of —1.02°, or 0.158°. If the salts are diluted to the same extent as the organic substances, there should be an additional rise in the freezing point equal to 15.5 per cent of —0.85°, or —0.132°. This would make the total change in the freezing point of the blood due to immersion in fresh water equal to 0.29°, but, as a matter of fact, a rise of 0.408° was noted on page 14. In other words, the change in the freezing point due to dilution alone does not account for the maximum change observed by actual experiment. How can the remainder of the change be accounted for?

The total loss in chlorine and probably in salts from the serum has been shown to be 25.7 per cent. In the preceding paragraph, 15.5 per cent of this loss has been ascribed to dilution. There remains 10.2 per cent, or —0.087°, which I conclude represents the amount lost by diffusion through the gill membranes. If 0.29° rise in the freezing point be due to dilution, and a further rise of 0.087° be due to diffusion, the two values combined account for a total rise of 0.377°. The observed rise was 0.408°.

Dakin ('08) in discussing work of a similar nature wrote, "Another interesting point in the above results is that reduction in salt contents of the blood as indicated by the chlorine contents is much greater than the lowering of the osmotic pressure would lead one to expect." This can now be explained in the following manner: If the loss in salts had been equal to the loss in organic substances then the percentage change in the freezing point would have been equal to the percentage change in these other substances. Since, however, the change in the salts is in excess of the change in the other substances, it follows that the percentage change in the freezing point of the blood is somewhat greater than the percentage change due to organic solutes and somewhat less than the percentage change in the salts. This is shown by the data. Thus there was a loss of 15.5 per cent in organic solutes, a loss of 25.7 per cent in salts, but only a loss of 21.9 per cent in the osmotic pressure of the blood. Hence, not only do the calculations of the change in the freezing point of the blood based on the results of chemical analysis confirm the general result ascertained, by the direct determination of the freezing point, but it is also possible to gain further insight into the nature of the changes produced.

It has been found that the blood is but slightly laked even at the time of death in fresh water. At the same time, the ratio of the volume of corpuscles to plasma increases. The corpuscles increase in volume. The accompanying slight trace of laking shows that while the corpuscles as a rule are swollen, a small number burst. In the swollen state it is possible that their oxygenating function is interfered with. This would also partially explain the effect on respiration.

At death in fresh water, the plasma is deficient in urea. Baglioni and Mines have shown that urea is a necessary ingredient of the selachian blood for the maintenance of normal cardiac activities. Baglioni concluded that it promoted systolic tonus. He found that other substances, such as cane sugar, cannot replace it, and that therefore urea is necessary for its chemical effect on heart tissue rather than for its osmotic contribution.

The deficiency of the blood in salts, however, is greater than in urea. Baglioni concluded that the sodium salts increase diastolic tonus. He found that an equal increase in urea and sodium chloride causes an increase in systolic and diastolic tonus up to a certain point beyond which cardiac activities come to a standstill. He concluded that in the proportions in which the salts are found in the blood, systolic tonus counteracted diastolic tonus and the interaction of the two was necessary for normal rhythmical contraction. It has been shown in the present paper that the balance normally present between these two substances is upset, for the blood is losing salts more rapidly than its urea. Loeb ('11) has called attention to the rôle of the salts of sodium, potassium, calcium and magnesium in the preservation of life. He has maintained the importance of the proportion in which they exist in sea-water. The same proportion of the same salts has been found by Macallum ('10) in the blood of animals representing different phyla. It has been shown in the present paper that the salts diffuse out through the gill membranes, and it is possible that the different ions pass out at different rates. Thus the sodium and magnesium ions may pass out first of all because of their speed of diffusion, and the potassium and calcium may pass out to a smaller extent and later. Thus the normal relations of these ions so necessary to the normal heart beat and to the activities of all tissues may be thus changed. A more rapid loss of salts on the part of the blood than on the part of the tissues leads to a disparity between the osmotic pressures of the two. The tissues absorb water, as shown, leading to an œdema. This interferes with their normal action—as, for example, the water rigor of muscle.

The marine invertebrates, because of the lack of a quickly acting regulative mechanism, are helpless in the event of a rapid change in the molecular concentration of the external medium. Though their range of movement is more restricted than that of the fishes, yet a regulative mechanism must have been developed in the case of those forms which have migrated into fresh water. Such a regulative mechanism is one of the mechanisms of adaptation.

The dog-fishes, on the other hand, are migratory. I think it probable that they are provided with a sensory apparatus by which they are made aware of marked decreases in the concentration of the sea-water, with the result that they avoid dilute media. The dog-fishes are provided in addition with an excretory apparatus which is able to regulate to a modified extent the osmotic pressure of the blood. The result of this activity of the kidneys is that the change in the osmotic pressure of the blood is always less than the change in the external medium. The kidneys conserve those substances which contribute to the molecular concentration of the blood and eliminate the excess of water. There is a limit, however, to this life-saving action of the kidney.

The effect of a stimulus depends not only upon its intensity but also upon the suddenness of it. Osmotic changes are induced more rapidly by a sudden than by a gradual change from sea-water to fresh water. In fact, in my experiments a sudden great change in the osmotic pressure of the external medium sometimes caused a rupture of the gill membrane at certain points with a resulting flow of blood. The gradual transition from sea-water to fresh water prevented this bleeding from the gills. Death occurs more quickly in such cases without a great change in the osmotic pressure of the blood. These are simply instances of a wider application of Du Bois Raymond's law of stimulation. But it has been shown (p. 28) that the osmotic change occurs through the gill membranes. These, however, are not strongly resistant to changes in the osmotic pressure of the external medium.

The reason that the dog-fish can withstand moderate changes in the external medium is not because it resists these perfectly, but because the organization of its protoplasm is of such a nature that life activities can continue even though the osmotic character of its blood is considerably modified. The heart of *Mustelus* continues to beat long after respiration has ceased after immersion in fresh water. *Squalus* and other elasmobranchs live in the dilute sea-water at the New York Aquarium: and yet the osmotic pressure of the blood of *Squalus,* while considerably above that of the harbor water, is still but nine-tenths of that found in fishes living in sea-water. The osmotic pressure of the blood of higher forms never has been proportionately reduced without serious impairment if not cessation of protoplasmic activities.

Moore ('08), in advancing strong arguments to show the failure of the membrane theory to account for the equilibrium between the cell and its environment, suggested that the cell was able to undergo reversible processes of association and dissociation with the constituents outside of it. Such association is in the nature of more or less stable chemical combinations which he terms adsorpates. For each cell there is a range of osmotic pressure within which partial association and discussion is possible, and within this range labile exchanges are possible.

This idea may be extended to explain why the tissues of the dog-fish, though normally adapted to an osmotic pressure of its blood approximately equal to that of the sea-water, is able to live in the dilute seawater of New York harbor. In such dilute water, the blood has an osmotic pressure represented by a freezing point of —1.70°. This represents the lowest osmotic limit of the blood at which the cells of the dog-fish can establish proper associations with the substances in the blood, or in other words at which the metabolic processes can take place. It is of interest to note that this freezing point, namely, —1.70°, is also the least noted in the case of the smooth dog-fish, *Mustelus,* at Woods Hole (see p. 7). Continuing Moore's conception, it is probable that —1.87° represents the optimum osmotic pressure at which the labile processes of association and dissociation can most perfectly take place. Greene ('05) implies the same idea, for he concludes that salmon having blood with an osmotic pressure widely different from the mean are in a pathological condition. Dakin ('08), Dekhuyzen ('04) and others who have determined the freezing points of teleost blood seem impelled to insist on its constancy; yet considerable variation appears in the actual results noted by them. Variations occur even in human blood at different times of day, as shown on page 6. Winter ('96) has maintained that metabolic processes would cease if the osmotic pressure of the blood should attain a stagnant dead level.

It should be observed in this connection that the freezing point of the blood of the dog-fish at the New York Aquarium remains at about —1.70°, while the water in which they live has a freezing point of about —1.00°. The animal is able to prevent a further lowering in the osmotic pressure of the blood. It cannot resist perfectly the change in the osmotic pressure of the external medium, but it is able to carry on life processes at the lower limit. It is possible to conceive that because of the dilute condition of the blood, the cell finds great difficulty in establishing normally stable associations. Life processes are continued, but with decreased efficiency. Indeed observation shows that the elasmobranchs at the New York Aquarium are less vigorous and hardy than those at Woods Hole.

The blood of the fishes living at the lower limit, namely, having a freezing point of —1.70°, is not as dilute as the blood of *Mustelus* at the time of death in fresh water. In fact, the change in the osmotic pressure of the blood due to dilution alone would cause a rise in the freezing point of the blood of about 0.30°. Therefore, mere dilution of the blood up to the point at which salts begin to diffuse out would pass the limit in the range in the osmotic pressures of the blood and cause death. This explains why the dog-fish failed to regain the normal freezing point of its blood on return to sea-water after a change of about 0.30° due to immersion in fresh water. Because of such a reduction in the osmotic pressure of the blood the constitution of the protoplasmic molecules is disturbed in part, and on the return to sea-water the normal relations fail to be regained.

Conclusions

The following conclusions regarding the osmotic relations of *Mustelus canis* seem to be warranted:

The osmotic pressure of the blood of the fish varies about an optimum represented by a freezing point of —1.87°.

The change in the osmotic pressure of the blood due to changes in the molecular concentration of the external medium depends,

1st, upon the time of immersion in the external medium, and,

2nd, upon the modification in the molecular concentration of the external medium.

The change in the osmotic pressure of the blood is not equal, but yet bears quite a constant ratio to the change in the molecular concentration of the external medium. The blood of *Squalus* living in brackish water has a higher osmotic pressure than that of the water in which it lives.

When a considerable modification in the osmotic pressure of the blood is brought about by immersion of the fish in solutions hypotonic or hypertonic to sea-water, the normal osmotic pressure of the blood is not regained by the return of the fish to sea-water.

The changes in the osmotic pressure of the blood take place through the gill membranes.

The osmotic pressure of the blood is not greatly modified by the abstraction of one-half the total quantity of blood in the body.

Although the blood is but faintly laked on immersion of the fish in fresh water, the corpuscles are swollen.

The resistance of the erythrocytes of elasmobranchs to hæmolysis is not much inferior to that of the marine teleosts and appears to be independent of osmotic relations of the corpuscles to its surrounding medium, nor does there appear to be any close relation between the resistance of the corpuscles to hæmolysis and the salt content of the plasma.

When *Mustelus* is immersed in hypertonic solutions of sea-water, not only does the osmotic pressure of the blood increase but also its chlorine content.

The specific gravity of the blood decreases on immersion of the fish in fresh water.

When the fish is immersed in fresh water, a certain amount of decrease in the osmotic pressure of the blood can be ascribed to dilution of the blood caused by the absorption of water through the gill membranes. In addition, a further change is due to diffusion of salts outward through the gill membranes, as is shown by the presence of considerable quantities of chlorine in the water in which the fish is immersed.

The tissues of the body tend to maintain the osmotic pressure of the blood by absorbing water from the hypotonic blood and this tends to raise the pressure.

By secreting rapidly a diluted urine, the kidneys also tend to maintain the normal osmotic pressure of the blood. By this process, the urea and a certain amount of the salts of the blood are conserved.

The changes in blood pressure due to immersion in fresh water are slight as compared with the effects upon respiratory and cardiac activity.

On immersion in fresh water, there is a gradual failure of respiration: this is marked by irregularly repeated spasmodic respiratory movements which increase in intensity for a period and then decline.

When the sea-water in which the fish is immersed is gradually changed to fresh water, the heart beat increases in amplitude and decreases in rate. The contractions gradually diminish in force, although the heart continues to beat faintly after respiration has ceased.

Coincident with and similar in character to the spasmodic movements of respiration, spasmodic contractions of the heart occur.

The normal osmotic pressure of the blood of *Mustelus* is maintained only by the organism remaining in sea-water. It is probably provided with a sensory apparatus by which it is able to avoid great modifications of the external medium. In slightly brackish waters, the osmotic pressure of the blood is diminished by the influx of water through the gill membranes; but because of the regulative activity of the kidneys and other bodily tissues, the changes are less than the changes in the external medium, and are still within the range of pressures compatible with life. With greater changes in the molecular concentration of the external medium the organism succumbs.

The gill membranes are probably not greatly injured by this absorption of water, for the animal continues to live indefinitely, as is shown by the elasmobranchs in the New York Aquarium. It may be concluded that the death of *Mustelus* is due to the following effects produced by immersion in fresh water: increased permeability of gill membranes; dilution of the blood; swelling of corpuscles; partial hæmolysis; excessive loss of salts from the blood; a fall of nearly one-fourth in the osmotic pressure of the blood; an associated œdema of the tissues, and a failure of respiratory and cardiac activities.

BIBLIOGRAPHY

BAGLIONI, S. Einige Daten zur Kentniss der quantitaven zusammensetzung verschiedener Körperflüssigkeiten von Seetieren (Fischen und einigen Wirbellosen). Hofmeister's Beitrag, IX, s. 50. 1907.

———. Zur Kenntniss des N-stoffwechsels der Fische. (Die Bedeutung des Harnstoffs dei Selachieren) Zentralblatt f. Physiologie, XX, 4, p. 105. 1906.

———. Beiträge zur allgemeinen Physiologie des Herzens. Zeitschrift f. Allgemeine Physiologie, VI, 1. s. 71. 1906.

BERT, P. Sur les phenomenes et les causes de la mort des animaux d'eau douce que l'on plonge dans l'eau de mer. Compt. rend., 73. 1871.

BOTTAZZI, F. La pression osmotique du sang des animaux marins. Arch. ital. biol., XXVIII, s. 61. 1897.

———. Sulla regolazione della pressione osmotica negli organismi animali. Arch. Fisiol., III, p. 416. 1906.

———. Resistenz dei corpuscoli rossi di Scyllium e de Sipunculus a cedere rispettivamente l'emoglobina e l'emertrina. Arch. Fisiol., III, p. 495. 1906.

———. Pressione osmotica e conduttiva elletrica a del succo musculare, del siero di sangue e dell'orina dei pesci. Arch. Fisiol, III, p. 547. 1906.

———. Origine dell' Urea nei selacii, Arch. Fisiol., V, p. 243. 1908.

———. Koranyi and Richter's-Physikalische Chemie und Medizin, Erster Band, p. 475, Leipzig. 1907.

BOTTAZZI, F., ET DUCCESCHI. Resistance des erythrocytes alcalinite du plasma et pression osmotique du sang des differentes classes des vertèbres. Archiv. ital. biol., XXVI, p. 161. 1897.

BOTTAZZI, PH., AND ENRIQUES, P. Ueber die Bedingungen des osmotische Gleichgewichts und des Gleichgewichtsmangels zwischen den organischen Flussigkeiten un dem äusseren Medium bei den Wasserthieren. I. Die Osmotischen Eigenschaften der Magenwand der Aplysien. Arch für Anat. und Physiol., Sup. Band, p. 109. 1901.

BUGARSKY AND TANGL. Untersuchungen über die molecularen Concentrations verhältnisse des Blutserums. Centralblatt f. Physiologie, XI, s. 301. 1897.

BUGLIA, G. Ueber die Regulierung der physicochemischen Eigenschafte des Blutes nach Injectionen von verschieden Lösungen. Biochem. Zeitschrift, XIII, p. 400. 1908.

DAKIN, W. J. Osmotic Concentrations of Blood of Fishes Taken from Sea Water of Naturally Varying Concentration. Bio-Chemical Jour., Liverpool, III, p. 258. 1908.

———. Variations in the Osmotic Concentration of the Blood and Cœlomic Fluids of Aquatic Animals Caused by Changes in the External Medium. Bio-Chemical Jour., Liverpool, III, 10, p. 473. 1908.

DEKHUYZEN, M. C. Ergebnisse von Osmotischen Studien. Bergens Museum, Aaborg. 1904.

———. Sur la pression osmotique dans le sang et dans l'Urine des poissons. Arch. nierl., X, p. 121. 1905.

DENIS. W. Metabolism Studies on Cold Blooded Animals. 1. The Urine of the Fish. Jour. of Biol. Chem., XIII, 2, p. 225. 1912.

FANO, G., ET BOTTAZZI, F. Sur la pression osmotique du serum et de la lymph en differentes conditions de l'organisms. Arch. ital. Biol., XXVI, p. 45. 1896.

FINDLAY, A. Physical Chemistry and its Applications in Medical and Biological Sciences. Longmans, Green and Co. 1905.

FREDERICQ, L. Sur la concentration moleculaire du sang et des tissus chez les animaux aquatique. Arch. de Biol., XX, p. 709. 1904.

GARREY, W. E. Osmotic Pressure of Sea Water and of Blood of Marine Animals. Biol. Bull., VIII, p. 257. 1905.

GREENE, C. W. Physiological Studies of the Chinook Salmon. Bull. U. S. Bureau Fisheries, XXIV, p. 431. 1904.

HAMMARSTEIN (MANDEL). A Text Book of Physiological Chemistry. John Wiley and Sons, New York. 1911.

HYDE, I. H. Effect of Salt Solutions on the Respirations, Heart Beat, and Blood Pressure in the Skate. Am. Journ. Physiol., XXIII, p. 201. 1909.

———. Localization of the Respiratory Center in the Skate. Am. Jour. Phys., X, p. 236. 1904.

JAPELLI, A. Rôle du tissu musculaire dans la regulation de la pression osmotique du sang. Arch. Intern. Physiol., IV, p. 369. 1906.

LANDOLT AND BÖRNSTEIN. Physikalisch-Chemische Tabellen, Berlin. 1905.

MACALLUM, A. B. The Inorganic Composition of the Blood in Vertebrates and Invertebrates and its Origin. 1910 Proc. of the Roy. Soc., B, 82, p. 602. 1910.

MINES, G. R. On the Relations to Electrolytes of the Hearts of Different Species of Animals. Journ. Physiol., XLIII, 6, p. 467. 1912.

MOORE, BENJ. On the Equilibrium Between the Cell and its Environment in Regard to Soluble Constituents, with Special Reference to the Osmotic Equilibrium of the Red Blood Corpuscles. Biochem. Jour., Liverpool, III, p. 55. 1908.

MOSSO, A. Ueber verschiedene Resistenz der Blut Körperschen bei verschiedenen Fischarten. Biol. Centralbl., X, p. 570. 1890.

NERNST. Theoretische Chemie, Sechste Auflage, p. 151. Stuttgart. 1909.

OVERTON. Neununddreissig Theses über die Wasserokonomie der Amphibien und die Osmotischen Eigenschaften der Amphibienhaut. Verhand. der Physikalisch-medicin Gesell. zu Würzburg, XXXVI. 1904.

PARKER, G. H. Influence of the Eyes, Ears and Other Allied Sense Organs on the Movements of the Dog-Fish, *Mustelus canis* (Mitchill). Bull. U. S. Bureau Fisheries, XXIX, p. 45. 1909.

QUINTON, M. R. Communication osmotique chez l'invertebres marins normal entre le mileau interieur l'animal et le mileau exterieur. Compt. rend., 131, p. 905. 1900.

———. Permeabilité de la paroi exterieur de l'invertebre marin non seulment a l'eau mais encore aux sels. Comp. rend., 131, p. 952. 1900.

RODIER, E. Observations et experiences comparatives sur l'eau de mer le sang et des liquides internes des animaux. Travaux des labor. de la stat. zool. a'Arcachon, p. 103. 1899.

SHELDON, R. E. The Reactions of the Dog-Fish to Chemical Stimuli. Journ. Comp. Neur. and Psych., XIX, 3, p. 273. 1909.

SIEDLECHI, M. Sur la resistance des epinoches aux changements de la pressione osmotique du mileau ambiant. Compt. rend., 137, p. 469. 1903.

SUMNER, F. B. Physiological Effects upon Fishes of Changes in the Density and Salinity of Water. Bull. U. S. Bureau Fisheries, XXV, p. 53. 1905.

TOWNSEND, C. H. Sixteenth Annual Report of the Director of the New York Aquarium. April, 1912.

VON SCHROEDER, W. Ueber die Harnstoffbildung der Haifische. Zeitschr. f. Physiol. Chem., XIV, s. 576. 1890.

WINTER, J. De la concentration moleculaire des liquides de l'organisme. Arch. de Physiol., VIII, p. 114. 1896.

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[Annals N. Y. Acad. Sci., Vol. XXIII, pp. 77–83. 29 May, 1913]

CORRECTIONS AND ADDITIONS TO "LIST OF TYPE SPECIES OF THE GENERA AND SUBGENERA OF FORMICIDÆ"

By William Morton Wheeler

Since my list of generic and subgeneric types of the Formicidæ was published,[1] Mr. Sievert Rohwer has kindly called my attention to some type determinations of earlier dates than those I recorded and especially to the genus *Cephalotes* Latreille, which has been incorrectly cited by Dalla Torre in his "Catalogus Hymenopterorum" and generally ignored by myrmecologists. Prof. Carlo Emery has called attention to a few omissions and incorrect determinations of types,[2] and I have myself detected several others. While seizing the opportunity to make corrections, I have added the types of a number of new genera and subgenera established during or since the publication of my paper. In this list of additions there are a number of subgenera of *Camponotus* recently published by Forel. Strangely enough, he does not designate the types, although nothing could have been more necessary in splitting up such a huge and perplexing genus as *Camponotus*. When he mentions several species belonging to one of these new subgenera, I have uniformly selected the first as the type, not because I am an unqualified adherent to the "first species rule," but because Forel probably intended to indicate the first species as the type.

Corrections

Aneleus Emery.—I cited *Solenopsis similis* Mayr as the type of this subgenus, supposing it to be monobasic, but this is far from being the case. Emery cites six species of *Pheidologeton* as belonging to *Aneleus*, and as he mentions *Ph. pygmæus* Emery as the first in his list, this should be regarded as the type, especially as the soldier or most characteristic phase of the oldest known species, *S. similis*, has not been described.

Atopogyne Forel.—Emery prefers to regard *Formica depressa* Latreille as the type of this subgenus, instead of *Crematogaster hellenica* Forel, the species I selected, because *depressa* is the most characteristic

[1] Annals N. Y. Acad. Sci., Vol. XXI, pp. 157–175. 1911.

[2] Les Espèces-Type des Genres et Sous-Genres de la Famille des Formicides. Ann. Soc. Ent. Belg., LVI, pp. 231–233. 1912.

species and because it was Forel's intention to regard it as the type, as he subsequently stated in a letter to Emery.

Azteca Forel.—The type of this genus is not *Tapinoma instabilis* F. Smith, but *Azteca instabilis* Forel (= *A. muelleri* Emery), as Emery maintains (Genera Insect. Fasc. 137, p. 31, 1912).

Cataglyphis Förster.—This should rank as an independent genus and not as a subgenus of *Myrmecocystus.*

Cephalotes Latreille.—The type is incorrectly cited as *Formica cephalotes* L. (= *Atta cephalotes*) instead of *F. atrata* L. (= *Cryptocerus atratus*). The genus *Cephalotes* was unfortunately regarded by Dalla Torre as a synonym of *Atta* Fabr., but it is evidently synonymous with and must replace *Cryptocerus,* as Mr. Rohwer maintains (*in litteris*). Latreille described *Cephalotes* in the third volume of his Hist. Nat. Crust. Insect., p. 357, which was published in 1802. The only species cited as an example is *Formica atrata.* On this same species he also based his genus *Cryptocerus* in the thirteenth volume of the same work, published in 1804 according to Mr. Rohwer, or 1805 according to Hagen (Biblioth. Ent., p. 453) and Dalla Torre. It is evident, therefore, that *Cryptocerus* is isogenotypic with the earlier *Cephalotes* and must be consigned to the synonymy.

Condylodon Lund.—The word "monobasic" should be added.

Cosmacetes Spinola.—The word "monobasic" should be added.

Crematogaster Lund.—Prof. Emery insists that the name of this genus should not be written *Cremastogaster,* because Lund, who mentions it only once, gives the word with a single *s,* and it is not certain that we are dealing with a typographical error. Emery also implies that Bingham was wrong in designating *Formica scutellaris* Olivier as the generic type. Lund cites no species in connection with *Crematogaster,* which is saved from being a *nomen nudum* only by the clear description of the abdomen, which exhibits peculiarities not found in any other genus of ants. As he had in mind only Brazilian species, Emery believes that one of these, e. g., *Formica acuta* Fabr., should be selected as the type. It might be contended, on the other hand, that in such a widely distributed and homogeneous genus as *Crematogaster,* it is better to select the common European form *C. scutellaris,* which is, moreover, closely related to the typical North American *C. lineolata* Say. At any rate, it is too late to make a change, because Bingham's designation, unless an earlier is found, will have to stand.

Eciton Latreille.—Shuckard (Swainson and Shuckard, Hist. & Nat. Arrang. Ins., p. 173. 1840) states that *Formica hamata* Fabr. is the type of this genus.

Formica L.—*Formica rufa* L. is given as the type of this genus by Girard (Traité Élém. d'Ent., II, p. 1011. 1879).

Gnamptogenys Roger.—My designation of *Ectatomma concinnum* F. Smith (*nec* Mayr) as the type of this subgenus is erroneous. Emery has rightly selected *G. tornata,* the first of two species described by Roger.

Holcoponera Mayr.—Now ranks as an independent genus.

Labidus Jurine.—According to Mr. Rhower, Latreille designated *L. latreillei* Jurine (=*Eciton* (*Labidus*) *cœcum* Latr.) as the type of this subgenus as early as 1810.

Leptothorax Mayr.—Emery selects *L. clypeatus* Mayr as the type of this genus, both because it was the first species described by Mayr and because *L. acervorum* Nylander has already been made the type of the subgenus *Mychothorax* by Ruzsky.

Myrmecia Fabricius.—Shuckard (Hist. & Nat. Arrang. Ins., p. 173. 1840) designated *Formica gulosa* Fabr. as the type of this genus.

Myrmica Latreille.—Girard designated *Formica rubra* L. as the type of this genus (Traité Élém. d'Ent., II, p. 1016. 1879).

Oecodoma Latreille.—*Formica cephalotes* L. is designated as the type of this genus by Shuckard (Hist. & Nat. Arrang. Ins., p. 174. 1840).

Rhytidoponera Mayr.—This now ranks as an independent genus. I selected *Ectatomma metallicum.* F. Smith as its type. Emery designates *E. araneoides* Le Guillou (=*rugosum* F. Smith) (Gen. Insect., Fasc. 118. 1911), because it is the first species cited by Mayr and because he, Emery, had previously (1879) based the subgenus *Chalcoponera* on *E. metallicum.* I do not regard the first reason as cogent; the second is, of course, valid and sufficient.

Tetramorium Mayr.—*Formica cæspitum* L. is designated as the type of this genus by Girard (Traité Élém. d'Ent., II, p. 1016. 1879).

Trigonogaster Forel.—Through a blunder of my amanuensis or of the printer the type of *Triglyphothrix* is repeated under this head. The correct type is *Trigonogaster recurvispinosa* Forel.

Additions

Allopheidole Forel. Mém. Soc. Ent. Belg., XIX, p. 237. 1912. (Subgenus of *Pheidole.*)

Type: *Pheidole kingi* Ern. André (by present designation).

Atopodon Forel. Rev. Suisse Zool., XX, p. 771. 1912. (Subgenus of *Acropyga.*)

Type: *Acropyga* (*Atopodon*) *inezæ* Forel. (First of three species by present designation.)

Atopula Emery. Ann. Soc. Ent. Belg., LVI, p. 104. 1912. (Subgenus of *Vollenhovia.*)

Type: *Atopomyrmex nodifera* Emery (designated by Emery).

Chalcoponera Emery. Ann. Mus. Stor. Nat. Genova, XXXVIII, p. 547. 1897. (Subgenus of *Rhytidoponera.*)

Type: *Ectatomma metallicum* F. Smith (designated by Emery).

Decapheidole Forel. Mém. Soc. Ent. Belg., XIX, p. 237. 1912. (Subgenus of *Pheidole.*)

Type: *Pheidole perpusilla* Emery (by present designation).

Emeryopone Forel. Rev. Suisse Zool., XX, p. 761. 1912.

Type: *Emeryopone buttel-reepeni* Forel (monobasic).

Forelomyrmex *nom. nov.* for **Janetia** Forel (1899), which is preoccupied by *Janetia* Kieffer (1896), a genus of Itoniidæ (*Cecidomyiidæ*).

Holcoponera Cameron. Whymper's Travels in the Andes, Suppl., p. 92. 1891. (= *Cylindromyrmex* Mayr.)

Type: *Holcoponera whymperi* Cameron = *Cylindromyrmex striatus* Mayr (monobasic).

Hylomyrma Forel. Mém. Soc. Ent. Belg., XX, p. 16. 1912. (Subgenus of *Pogonomyrmex.*)

Type: *Pogonomyrmex* (*Hylomyrma*) *columbicus* Forel (designated by Forel).

Isopheidole Forel. Rev. Suisse Zool., XX, p. 765. 1912. (Subgenus of *Pheidole.*)

Type: *Aphænogaster longipes* F. Smith var. *longicollis* Emery (monobasic).

Leptomyrmula Emery. Genera Insect., Fasc. 137, p. 16, *nota*. 1912.

Type: *Leptomyrmex maravignæ* Emery (monobasic).

Machaerogenys Emery. Gen. Insect., Fasc. 118, p. 100. 1911. (Subgenus of *Leptogenys.*)

Type: *Leptogenys truncatirostris* Forel (designated by Emery).

Mesomyrma Stitz. Stitzb. Gesell. naturf. Freunde Berlin, p. 363. 1911. (Subgenus of *Podomyrma.*)

Type: *Podomyrma* (*Mesomyrma*) *cataulacoidea* Stitz (monobasic).

Metapone Forel. Rev. Suisse Zool., XIX, p. 447. 1911.

Type: *Metapone greeni* Forel (monobasic).

Myrmamblys Forel. Mém. Soc. Ent. Belg., XX, p. 90. 1912. (Subgenus of *Camponotus.*)

Type: *Camponotus reticulatus* Roger (by present designation).

Myrmentoma Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus.*)

Type: *Formica lateralis* Olivier (by present designation).

Myrmepomis Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Formica sericeiventris* Guérin (by present designation).

Myrmeurynota Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus eurynotus* Forel (by present designation).

Myrmobrachys Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (Subgenus of *Camponotus*.)

Type: *Formica senex* F. Smith (by present designation).

Myrmogigas Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (= *Dinomyrmex* Ashmead; subgenus of *Camponotus*.)

Type: *Formica gigas* Latreille (by present designation).

Myrmogonia Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus laminatus* Mayr (by present designation).

Myrmophyma Forel. Mém. Soc. Ent. Belg., XX, p. 91, 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus capito* Mayr (by present designation).

Myrmorhachis Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus polyrhachoides* Forel (by present designation).

Myrmosaga Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus kelleri* Forel (by present designation).

Myrmosericus Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (Subgenus of *Camponotus*.)

Type: *Formica rufoglauca* Jerdon (by present designation).

Myrmosphincta Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Formica sexguttata* Fabricius (by present designation).

Myrmotarsus Forel. Mém. Soc. Ent. Belg., XX, p. 92. 1912. (Subgenus of *Camponotus*.)

Type: *Formica mistura* F. Smith (by present designation).

Myrmothrix Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (Subgenus of *Camponotus*.)

Type: *Formica abdominalis* Fabricius (by present designation).

Myrmotrema Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (Subgenus of *Camponotus*.)

Type: *Camponotus foraminosus* Forel (by present designation).

Myrmoturba Forel. Mém. Soc. Ent. Belg., XX, p. 91. 1912. (Subgenus of *Camponotus.*)

Type: *Formica maculata* Fabricius (by present designation).

Neoformica subgen. nov. (Subgenus of *Formica.*)

Type: *Formica pallidefulva* Latreille (by present designation).

Octostruma Forel. Mém. Soc. Ent. Belg., XIX, p. 196. 1912. (Subgenus of *Rhopalothrix.*)

Type: *Rhopalothrix simoni* Emery (by present designation).

Odontopelta Emery. Genera Insect., Fasc. 118, p. 101. 1911. (Subgenus of *Leptogenys.*)

Type: *Leptogenys (Lobopelta) turneri* Forel (monobasic).

Pachysima Emery. Ann. Soc. Ent. Belg., LVI, p. 97. 1912. (Subgenus of *Sima.*)

Type: *Sima æthiops* F. Smith (designated by Emery).

Parectatomma Emery. Genera Insect., Fasc. 118, p. 44. 1911. (Subgenus of *Ectatomma.*)

Type: *Ectatomma triangulare* Mayr (designated by Emery).

Pentastruma Forel. Entom. Mittheil., I, p. 51. 1912.

Type: *Pentastruma sauteri* Forel (monobasic).

Phasmomyrmex Stitz. Mitth. Zool. Mus. Berlin, V, p. 146. 1910. (Subgenus of *Camponotus.*)

Type: *Camponotus buchneri* Forel (monobasic).

Physocrema Forel. Mém. Soc. Ent. Belg., XIX, p. 220. 1912. (Subgenus of *Crematogaster.*)

Type: *Crematogaster inflata* F. Smith (by present designation).

Poneracantha Emery. Ann. Mus. Stor. Nat. Genova, XXXVIII, p. 548. 1897. (Subgenus of *Ectatomma.*)

Type: *Ectatomma (Poneracantha) bispinosum* Emery (monobasic).

Pristomyrmecia Emery. Genera Insect., Fasc. 118, p. 21. 1911. (Subgenus of *Myrmecia.*)

Type: *Myrmecia mandibularis* F. Smith (designated by Emery).

Proatta Forel. Rev. Suisse Zool., XX, p. 768. 1912.

Type: *Proatta butteli* Forel (monobasic).

Promyrma Forel. Rev. Suisse Zool., XX, p. 764. 1912.

Type: *Promyrma butteli* Forel (monobasic).

Promyrmecia Emery. Genera Insect., Fasc. 118, p. 19. 1911. (Subgenus of *Myrmecia.*)

Type: *Myrmecia aberrans* Forel (designated by Emery).

Psammomyrma Forel. Mém. Soc. Ent. Belg., XIX, p. 237. 1912. (Subgenus of *Dorymyrmex.*)

Type: *Dorymyrmex planidens* Mayr (by present designation).

Stegomyrmex Emery. Ann. Soc. Ent. Belg., LVI, p. 99. 1912.
Type: *Stegomyrmex connectens* Emery (monobasic).

Årataner Emery. Ann. Soc. Ent. Belg., LVI, p. 103. 1912.
Type: *Atopomyrmex foreli* Emery (designated by Emery).

Tetramyrma Forel. Rev. Suisse Zool., XX, p. 766. 1912. (Subgenus of *Dilobocondyla.*)
Type: *Dilobocondyla* (*Tetramyrma*) *braunsi* Forel (monobasic).

Trachymesopus Emery. Genera Insect., Fasc. 118, p. 84. 1911. (Subgenus of *Euponera.*)
Type: *Formica stigma* Fabricius (designated by Emery.)

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A CONTRIBUTION TO THE GEOLOGY OF THE WASATCH MOUNTAINS, UTAH

BY

Ferdinand Friis Hintze, Jr.

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A CONTRIBUTION TO THE GEOLOGY OF THE WASATCH MOUNTAINS, UTAH [1]

BY FERDINAND FRIIS HINTZE, JR.

(*Read by title before the Academy, 5 May, 1913*)

CONTENTS

[1] Manuscript received by the Editor, 26 April, 1913.

Introduction

The general geological features of the Wasatch Mountains have long been known from the comprehensive reports of the early federal surveys. Since these general studies were made, several special problems have been investigated, with the result that many new facts have been added, in the light of which, many of the first conceptions have been greatly modified.

One of the most important of these later observations is concerned with the structure. The complicated tectonic features of this remarkable range are only now beginning to be appreciated. The finding of large overthrusts in the vicinity of Ogden by Blackwelder in 1909 and the tracing of the great Bannock thrust from southern Idaho south into the Wasatch range accomplished by Richards and Mansfield of the U. S. Geological Survey within the last year or two have added much importance to this phase of the structure. Boutwell had previously discovered overthrusts in the Park City district, but they were thought to be local features and were not greatly emphasized.

As might be expected, the unravelling of the structure has had an important bearing upon the stratigraphy of the range, especially since the regions in which the overthrusts have been found were those that furnished the type sections to the early workers. The repetition of beds brought about by overthrusting escaped the attention of the Fortieth Parallel geologists, who gave the first unified account of the stratigraphy, and their section is therefore subject to correction.

It is the purpose of the writer to present in this paper a number of facts that were observed in the summer of 1912 in the central part of the Wasatch range, particularly in Big and Little Cottonwood Canyons, and to discuss the structure and stratigraphy of that region. The discovery of a great overthrust at Alta, in Little Cottonwood Canyon, has led to a new conception of the stratigraphy as well as the structure of this part of the range. The finding of many new fossil species has shed important light on the age of the paleozoic rocks, and the discovery of several disconformities has enabled the writer to subdivide the series into several new formations. Observations on the physiographic features of the central Wasatch have afforded interesting results on the present state of dissection of the Wasatch block mountain and have suggested an explanation of the principal drainage lines of the region. Other problems are partly solved, and much work will still have to be done before a complete account of the many interesting geological phenomena here shown can be given.

The writer desires to thank the mining men of South Fork and Alta most heartily for the support and assistance which they generously extended to him during his field work. While it does not seem possible to mention the names of all who have rendered help, the writer cannot forbear to acknowledge the cordial treatment shown him by Mr. Green of the Tar Baby Mining Company and Mr. Barney of the Cardiff Mining Company in South Fork, and at Alta by Mr. Blake of the Columbus Consolidated, Mr. Lemmon of the Columbus Extension, Mr. Jacobson of the Alta Consolidated, Mr. Godbe and Mr. Burton of the Michigan Utah, Mr. Gabrielson of the South Hecla and Mr. Stillwell of the Emma. To the managers and directors of these mines, the writer is grateful for the privilege of visiting the various properties and studying the ore deposits.

To the several members of the Department of Geology at Columbia, the writer feels greatly indebted for many helpful suggestions in the preparation of the report. To Professor Amadeus W. Grabau is due special thanks for the encouragement he has given from the very outset. Throughout the laboratory work, and especially on the paleontologic and stratigraphic side, he has manifested great interest in the results as they appeared. His kindly criticism has been of much value and assistance in formulating the conclusions here drawn. To Professors D. W. Johnson and C. P. Berkey, the writer is indebted for many valuable criticisms relative to the physiographic and petrographic features of the work.

Physiography

ORIGIN OF THE WASATCH MOUNTAINS

Immediately following Cretaceous time, the present Great Basin province was the scene of dynamic disturbances through which numerous mountain ranges were formed by the processes of folding and overthrusting. During early Tertiary time, the folds were truncated by erosion and the surface was reduced to an aspect of low relief. Then followed a period marked by profound faulting, the lines of movement being principally in a north-south direction, but with many cross fractures, which resulted in the formation of great fault-block mountains. These were characterized by relatively simple external features but with complex internal structure. The most easterly, and one of the most continuous of these fault-block masses, is the present Wasatch range.

When newly formed, the Wasatch block had a steep western face and a long gentle eastern back slope. It was greatly elongated in a north-south direction, extending from central Utah northward for almost 200 miles. The width as measured from its fault face on the west to its eastern border was about 25 miles. Its height was mainly due to vertical displacement along the great fracture line on the west. This dimension was no doubt cumulative and due to periodic uplift, the aggregate throw probably reaching 10,000 feet. The line of greatest elevation or crest of the block was near the western margin.

DISSECTION AND DRAINAGE

The dissection of such a block must have been initiated by the consequent streams which flowed down the two unequal slopes to the east and west. The valleys developed by these opposed streams would thus be transverse to the principal direction of the range, and when fully developed would divide it into a series of roughly parallel east-west ridges on each slope, leading from the main divide to the two margins of the block mountain. The unequal declivity of the two sets of streams would in time cause a migration of the divide toward the center line of the block, if the structure and materials were not essentially different and the base levels were at the same elevation on both sides. If the base level on the east were higher than the one on the west, the divide would come to rest nearer the eastern border, and the valleys and ridges west of it would be longest and most prominent. Some of the most powerful streams on the west slope might even cut entirely through the divide and send out lateral subsequent tributaries that would capture the east flowing consequents and lead them westward into the Salt Lake Basin. When once established, these master streams would continue to push eastward into the region beyond the Wasatch, gradually acquiring more and more drainage territory.

In the light of these theoretical considerations, we may examine the present maturely dissected Wasatch block mountain for some of the larger features due to its original form and subsequent dissection.

The main crest line of the Wasatch extends in a general north-south direction and stands at a variable height of from 3000 to 8000 feet above the level of the Bonneville Basin to the west. It is situated near the western border of the block and is marked by a succession of lofty peaks which crown the western terminations of a series of ragged ridges that lead westward from the main divide. This divide is situated from two to six miles east of the crest line, being often nearer the eastern border of the range than the western. This is especially noticeable in the central Wasatch. Here the divide is also lower than the crest by more than a thousand feet.

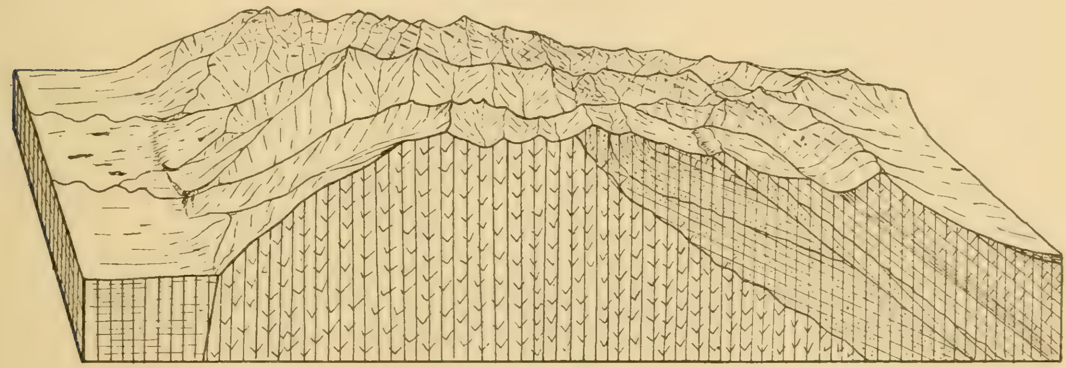

FIG. 1. STEREOGRAM OF A PORTION OF THE CENTRAL WASATCH MOUNTAINS, UTAH

Shows a maturely dissected block mountain with a steep western fault face and a gentle eastward back-slope. The main gorges are Big and Little Cottonwood Canyons, heading near the eastern margin of the block, and representing principally obsequent stream channels.

To the east, a similar series of ridges and intervening gorges lead off from the divide. A significant difference is to be noted here between the slope of the tops of the ridges east of the divide and those to the west. East of the divide, the ridges slope down to the level of high-lying basins, while westward they rise to the crest line and then suddenly break off to the Salt Lake plain. The tops of the ridges from the crest eastward descend gradually to the divide, and, crossing over it, they continue to become lower until they reach the eastern valley levels. They thus indicate the original back slope of the block, though they do not preserve any of the undissected upland surface. The present eastward slope of the ridge tops is not a very noticeable feature when viewed from the high peaks on the crest, the inclination being but a few degrees and appearing almost horizontal to the eye. From the more rapid erosion that has been going on along the crest line, however, it is safe to infer that the original back slope was of greater inclination, probably as much as 10 or 15 degrees.

The migration of the divide from the crest line toward the eastern margin of the block is most pronounced in the central part of the range. Big and Little Cottonwood canyons are good examples of long and deep valleys pushed back from the western face of the range well toward its eastern margin. The streams which have cut them have a more direct course to the base level of the region than those on the opposite side of the divide. This advantage has enabled them to send the divide east of the center line, where it should be expected to come to rest if the stream grades were equal in both directions (see Fig. 1).

At present, the Salt Lake Basin is the base level for the drainage of the east slopes as well as the west. The two through going streams, the Provo and Weber Rivers, bring the eastern drainage by long round-about courses back into the Bonneville Basin. No special field work has been done by the writer to determine the conditions which have established these streams in their present courses, but the thought suggests itself very strongly that they began as Big and Little Cottonwood creeks did to cut headward, and being more successful penetrated far enough to capture all of the eastern drainage of the central Wasatch and much of the western Uintas and the plateau region to the north and south of the Uintas. Their headwaters approach each other very closely at the western end of the Uinta uplift and are here separated by a low divide near the southern limit of the Kamas prairie. This divide becomes more pronounced as we follow it westward, rising as a high ridge between Parley's Park and Provo, or Heber Valley, and eventually culminating in Clayton Peak on the Wasatch divide, at the head of Big Cottonwood Canyon. The eastern slope of the Wasatch in this neighborhood is thus drained by two river systems which lead off in opposite directions, at length turning westward and cutting across the Wasatch to the Bonneville Basin. The small consequent streams which lead north-east and south-east from the Wasatch divide on opposite sides of Clayton Peak have the disadvantage of a long detour to the base level and have therefore been unable to cope with the streams west of the divide which have a much shorter and more direct course to the same base.

Structure and hardness of the rocks seem to have exercised only a minor amount of control in the determination of the position of the stream channels west of the divide. In Big Cottonwood Canyon, where the hardest rocks of the region are exposed, the stream seems to have cut indifferently across the beds in a peculiar diagonal fashion in the lower half of its course. In the upper half, it has much less fall and follows the strike of the beds more closely. The rocks here are limestones, shales and sandstones, while in the lower and steeper part of the canyon they pass into hard quartzites and slates.

It thus seems to be a fact that the structure and hardness of the rocks in the upper part of the canyon have had a somewhat greater influence on the course of the stream than in the lower part. Little Cottonwood Canyon is developed for the most part in granite of a very hard and homogeneous character. The course of the canyon is parallel to Big Cottonwood, where both structure and heterogeneous rocks enter into the problem. It is apparent that there must be some other cause operative to produce the correspondence. The chief determining factor seems to have been the original form of the block mountain. The western consequent streams on the steep fault face developed their channels transverse to the main north-south trend of the block, their direction being determined by the slope primarily. If the block was rapidly uplifted, the high gradient of the streams would be quite sufficient to cause them to cut back independent of the structure and kinds of rock. The direction of back-cutting would be at right angles to the front of the block, and as this was somewhat irregular, being curved in places, the stream courses should show some irregularity in direction. This indeed is the case. Where the fault face forms a great curve, as it does southeast of Salt Lake City, the canyons show a marked tendency to take off in the direction of the extended radii of the arc, as should be expected.

GLACIATION

After the Wasatch block mountain had been maturely dissected by stream action as briefly outlined above, Alpine glaciation set in during the Pleistocene period. Many of the deep V-shaped gorges were hollowed out into broad U-shaped valleys of striking outline. The best known example is Little Cottonwood, but there are many others in the upper parts of the large canyons. The upper half of Big Cottonwood is a deep U-trough with many hanging valleys on both sides. The heads of the canyons were widened into broad catchment basins with steepened sides. The divides were greatly sharpened in many places. Altogether, the topography was modified to a considerable extent in the central Wasatch, especially at the higher elevations near the heads of the canyons.[2] Numerous lakes due to glacial damming and the plucking action of the ice by which rock basins of considerable depth were formed are to be found at the heads of the larger canyons. Good examples of *roche moutonneés,*

[2] For a map showing the location of the principal glaciers and their catchment basins, as well as a brief account of the glaciation in the Wasatch, see ATWOOD: U. S. Geol. Surv. Prof. Pap. No. 61.

rock steps, and various other features due to glaciation are of frequent occurrence (see Plate I, Fig. A).

Since the disappearance of the glaciers, erosion has been slight. The streams have cut through the loose moraines in some places, but where they have been flowing on solid rock beds, they have cut but faint notches. These modifications are negligible as compared with the preglacial and glacial erosion which produced mature dissection.

Stratigraphy

Introductory Statement

The first works of importance on the general stratigraphical succession in the Wasatch Mountains are those of the King[3] and Hayden[4] surveys in the late seventies. They are to-day the only comprehensive account that we have dealing with the great range of sediments there exposed. Being general in their treatment, they have left many details to be supplied by closer investigations, such as are carried on within smaller quadrangles where the necessary time is taken to work out structural problems as well as to observe the general sequence of beds. American stratigraphy offers many examples of the mistakes that are so easily made by following the law of superposition without due regard to structure. Unrecognized repetition of beds by folding and faulting has often led to serious errors in estimating the real thickness and succession of formations. Within the limited time that was allotted to the comparatively few workers on these early surveys, a wonderful amount of field work was done, and magnificent reports, well illustrated with maps and sketches, were issued, which, though they are now known to be wrong in many cases, still serve as the best introduction to the systematic geology of the range.

In presenting a generalized account of the stratigraphy of the Wasatch Mountains, the Fortieth Parallel geologists seem to have taken the sections which showed the thickest development of the rocks of the various systems. The sections exposed in Weber Canyon and a few miles to the north in Ogden Canyon, together with those found in Big and Little Cottonwood Canyons, sixty miles to the south, seem to have been chosen as the types for the Paleozoic rocks. Especially the latter seems to have made a wonderful impression upon King, who introduces it thus: "I will now give a section observed between the mouth of Cottonwood Canyon

[3] U. S. Geol. Expl. 40th Par., vols. I and II, 1877, and Vol. III, 1878.
[4] U. S. Geog. and Geol. Surv. of the Territories.

and Parley's Park, the most extended and instructive stratigraphic exhibition of the Paleozoic series in the Fortieth Parallel area." [5]

It now appears that the Ogden area, recently visited by Blackwelder[6] and some of his colleagues from the University of Wisconsin, and the Cottonwood Canyon district, covered by the writer last summer, are similarly characterized by complicated structures involving large overthrusts which duplicate the rocks of the lower members of the Paleozoic series and give an apparent thickness which is much too great. Blackwelder has shown that the Ogden quartzite of Hague and Emmons does not exist as originally defined. Elsewhere in this report, it is shown that the Ute

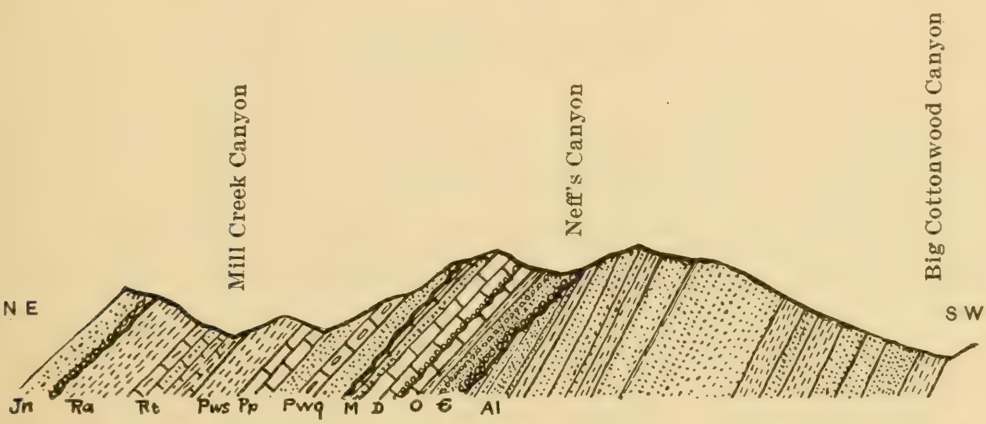

FIG. 2. SECTION EXPOSED BETWEEN THE MOUTH OF BIG COTTONWOOD AND THE HEAD OF MILL CREEK CANYONS

Al = Algonkian. C = Cambrian. O = Ordovician. D = Devonian. M = Mississippian. Pwq = Penn. Weber quartzite. Pp = Penn. Park City formation. Pws = Permian Woodside shale. Tt = Triassic Thaynes formation. Ta = Triassic Ankareh shale. Jn = Jurassic Nugget sandstone.

limestone of supposed Silurian age also has no existence as such in the central Wasatch, but is in reality the lower part of the Wasatch limestone reported as belonging to the Carboniferous. It seems strange that this relation should not have been discovered by the early workers on account of the marked contrast between the sequence of beds near Alta in Little Cottonwood Canyon and that seen across the divide to the north in Big Cottonwood Canyon.

BIG COTTONWOOD SECTION

At the mouth of Big Cottonwood Canyon is exposed the base of the great section of Paleozoic and Mesozoic rocks above referred to by King. Beginning on the strike of the beds which stand at a high inclination

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[5] C. KING: U. S. Geol. Expl. 40th Par., Sys. Geol., Vol. I, p. 165. 1878.

[6] E. BLACKWELDER: "New Light on the Geology of the Wasatch Mountains, Utah," Bull. G. S. A., Vol. 21, pp. 517-542. 1910.

(dip N. 60°), the great canyon holds a general course N. 70° E. for nearly eight miles, slowly truncating the edges of the successively higher beds, which as we go east gradually change their strike toward the south. From its mouth for a distance of about six miles, the canyon is walled by brown and yellowish quartzites interspersed with thick beds of black and purplish blue slates. The upper six miles of the canyon show the post-Cambrian formations, the general continuity of the beds being seriously broken only at one point, opposite South Fork of Mill D. The top of the section passes beyond the northeast divide of the canyon into the northwest corner of the Park City district.

QUARTZITE-SLATE SERIES

The great quartzite and slate series is succeeded below by gneiss and schist or granite. The igneous nature of the granite contact was not recognized by the Fortieth Parallel geologists, who mapped the granite as Archean and described the contact as one of sedimentary unconformity. The quartzite succession was assigned to the Cambrian, including the lowermost exposures. In describing the rocks referred to the Cambrian in his recapitulation of the Paleozoic, King[7] says:

"Thus far among the reported occurrences of the rocks of this horizon in the Cordilleras, the locality at the mouth of Big Cottonwood Canyon must remain as the finest example and the stratigraphical type. The lowest member—the Cottonwood slates, a group about 800 feet thick, which here rests upon highly metamorphic Archean schists—has thus far yielded no organic forms. The rocks are dark blue, dark purple, dark olive green and blackish argillites, all highly silicious and as a group sharply defined from the light-colored quartzite schists which conformably overlie them. This second group, by far the greatest of the whole Cambrian series, is a continuous zone of schists which have a prevailing quartzite character, though varied with considerable amounts of argillaceous matter. From 8000 to 9000 feet thick, it has a general uniformity of lithologic condition from bottom to top. . . . The prevailing colors of this member are gray, greenish gray, drab and pale brown, never dark colors. Conformably overlying it are 2500 to 3000 feet of cream and salmon color and white quartzites and quartzofelsites. Occasional sheets of conglomerate are seen in the quartzites not far below the summit of the Cambrian."

A few years later, in the course of his studies of the Cambrian sections of the Cordilleras, Dr. C. D. Walcott[8] visited Big Cottonwood Canyon, examining the quartzite series in more detail and re-measuring the sec-

[7] C. King: U. S. Geol. Expl. 40th Par., Vol. I, pp. 229-230. 1878.

[8] C. D. Walcott: "Second Contribution to the Studies on the Cambrian Faunas of North America," Bull. U. S. Geol. Surv. No. 30, pp. 38-39. 1886.

tion. Walcott's section[9] is inverted, as originally published, and is here given in the natural order, as follows:

Big Cottonwood Section

	Feet
14. Superformation: Mixed sandy and calcareous rocks which rest conformably on 13 of the section and carry a fauna which refers it to the lower Silurian (Ord).	
13. Hard, silico-argillaceous shales, a little sandy in places	250
Fossils: At the base, *Cruziana* sp. associated with *Olenellus gilberti;* 100 feet higher up, a band of shale afforded *Linguella ella, Kutorgina panula, Hyolithes billingsi, Leperdita argenta, Ptychoparia quadrans* and *Bathyuriscus producta.*	
12. Gray compact quartzitic sandstone	3,000
11. Purplish and reddish brown quartzitic sandstone	75
10. Gray compact quartzitic sandstone	700
9. Black, sandy, arenaceous, slightly micaceous shale	75
8. Light gray quartzite and quartzitic sandstone, in layers varying from 10 feet to 2 inches, the thin layers occurring as partings between the more massive bands of layers. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur	2,700
7. Arenaceous and argillaceous slates, black, bluish black, drab and yellowish green. The exposure is extensive, the opportunity for finding fossils excellent, and the slates afford a beautiful matrix for their preservation, but none were oberved	700
6. Light gray quartzite and quartzitic sandstone, in layers varying from 10 feet to 2 inches. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur	200
5. Hard, black, arenaceous shale, with specks of mica on the surfaces. Quartzite and shale intercalated near the base	1,000
4. Light gray quartzite and quartzitic sandstone in layers, varying from 10 feet to 2 inches. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur	700
3. Purplish, thin bedded sandstone, with bands of greenish yellow argillaceous shale near the summit	700
2. Massive bedded light gray quartzite	1,000
1. Black arenaceous shale, showing mud-markings and mud cracks, ripple marks	900
Total	12,000

Age of Series

From the occurrence of the *Olenellus* fauna in the shale member at the top of the series and the apparent conformity of the entire succession of

[9] The section is given here as corrected by Dr. Walcott in his Correlation Papers, Bull. U. S. Geol. Surv. No. 81, p. 319. 1891.

quartzites and shales, Walcott was led to place the whole 12,000 feet of strata in the Lower Cambrian. The Fortieth Parallel geologists, reasoning that the granite at the base was pre-Cambrian in age and separated from the quartzite series by a great unconformity, also assigned it to the Cambrian period. It is significant that the description given by King of the upper part of the section includes sheets of conglomerate, which, however, Walcott does not mention. These occur in a succession of coarse sandstones, the individual pebbles being small, usually less than half an inch in diameter. Blackwelder[10] has called attention to the strong lithological resemblance of these pebbles to the bright colored quartzites farther down in the series. He has also pointed out the fact that the section which is here 12,000 feet thick is much thinner to the north and that it is subject to rapid variations of thickness within short distances. These facts are taken to suggest the existence of an unconformity within the quartzitic series. At a horizon roughly estimated to be 1500 feet below the top of the quartzite in Big Cottonwood, Blackwelder reports the existence of a well-marked basal conglomerate, which he represents as lying upon the truncated edges of the lower members, showing, however, little angular discordance between the two sets of beds. This old erosion surface is taken as the base of the Lower Cambrian, marking the separation of the Cambrian from the Algonkian.

At the head of South Fork, near the Rexall mine, the writer found a heavy conglomerate composed of large, well-rounded quartzite and gneiss bowlders lying upon a very black rock of strange characteristics, the description of which will be given later. Overlying the conglomerate are 700 feet of well-bedded white quartzite, showing several sheets of fine conglomeratic material. Above this quartzite is a shale 125 feet thick, and superjacent to this comes the lowest limestone series. Tracing the conglomerate northward, the underlying black formation gradually thins out and the conglomerate comes to rest on the next lower bed of white quartzite. Passing west of Kessler's Peak, this contact travels down the east face of Mineral Fork and crosses Big Cottonwood Canyon, where Blackwelder saw it, a short distance below the Maxfield mine. Maintaining a fairly constant distance below the top of the series, the contact rises rapidly on the north wall of Big Cottonwood Canyon and crosses the divide into Neff's Canyon just south of the head of that basin. Curving gradually to the west, it crosses the crest of the range near the head of Tolcats Canyon and descends rapidly to the base of the mountain in Salt Lake Valley. From the starting place at the head of South Fork, it may

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[10] E. Blackwelder: "New Light on Geology of Wasatch Mountains, Utah," Bull. G. S. A., Vol. 21, p. 520. 1910.

be traced southward through the Alta basin at the head of Little Cottonwood Canyon, into American Fork Canyon.[10a] At Santaquin, near the Union Chief mine 40 miles to the south, it is seen again, being there 600 feet below the top of the series. The black formation on which it rests at the head of Little Cottonwood Canyon seems to be absent everywhere within a few miles to the north and south of that place, not appearing in Big Cottonwood Canyon, nor at Santaquin to the south. From its occurrence thus traced for about 50 miles, it may safely be taken to be of wide distribution. That it truncates the lower beds, producing extraordinary differences in their thickness within short distances, is also clear from the rapid disappearance of the black member, above referred to, and from the fact that northward at Willard, Utah, the conglomerate rests directly on Archean gneiss. The possibility of original inequality of thickness must be taken into account in connection with the thinning of the lower series. The uniform thickness and wide distribution of the quartzite and shale member overlying this dividing plane, taken together with the great variation in thickness of the lower series, seem to imply the widespread truncation of the lower beds and their reduction practically to a peneplain before the upper beds were deposited. The complete removal of the great quartzite series over considerable areas must have required much time. A great gap therefore separates the Lower Cambrian quartzite at the top of the series from the great quartzite and shale series underlying it, and the two must be of distinctly different ages.

Accepting Walcott's fossil evidence of the presence of Lower Cambrian strata above the unconformity, it seems only proper to regard the quartzite-slate series below as of pre-Cambrian, and probably Algonkian age. It would then correspond to the Belt series of Montana and the Grand Canyon series of Arizona, in both of which the Cambrian strata are separated from the pre-Cambrian formations by similar unconformities.

A very different view is held by Daly and others, namely, that the oldest Cambrian fossils in the Rocky Mountains are Middle Cambrian and that the Brigham quartzite is of that age. The unconformity is regarded as representing only a brief time interval, and the great quartzite-slate series is made early Cambrian and not Algonkian in age. This view seems to call into question the faunal evidence upon which the presence of Lower Cambrian strata at the top of the series is based. Dr. Walcott very kindly supplied the writer with photographs of two specimens of *Olenellus gilberti*, which he found at the base of the shale bed, and there seems to be no reason to doubt their correct identification. A diligent search in all

[10a]. See Plate I, fig. B.

the shale beds by the writer was not rewarded by the discovery of Cambrian fossils within the Cottonwood district. At Ophir, in the Oquirrh Mountains, and at Santaquin, the Middle Cambrian fauna which Dr. Walcott found 100 feet above the *Olenellus* fauna in Big Cottonwood Canyon are also found, and at least in one place at Ophir in the same relation to the Lower Cambrian fossil horizon. A later search at Santaquin may reveal the *Olenellus* fauna there.

If we accept *Olenellus gilberti* as the index fossil of the Lower Cambrian, then it seems that Daly must be mistaken in the statement that that

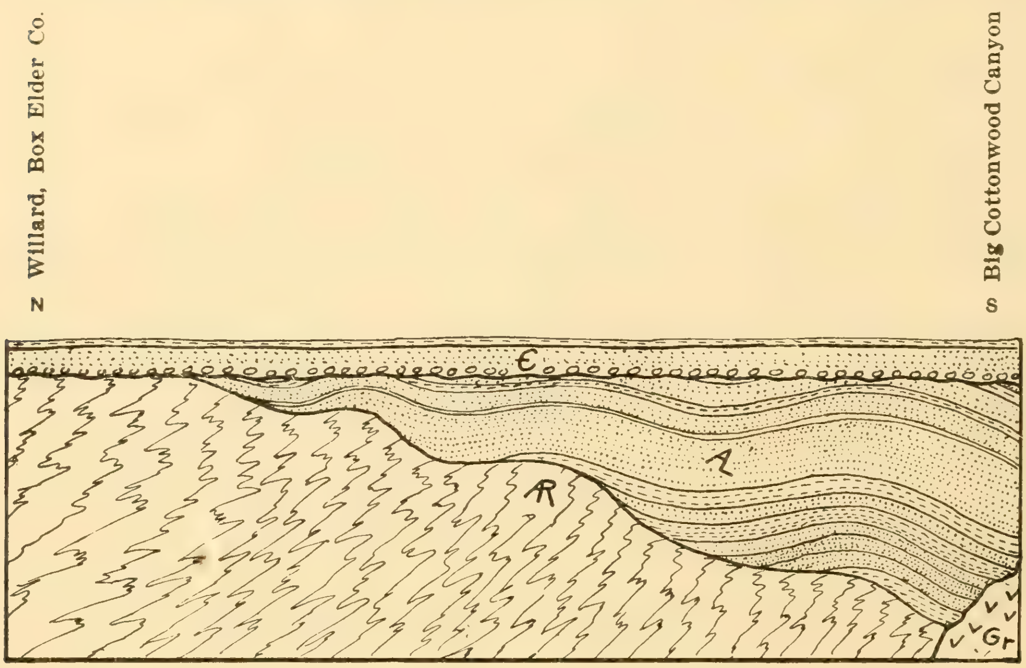

FIG. 3. SECTION FROM BIG COTTONWOOD CANYON NORTHWARD TO WILLARD, BOX ELDER CO., UTAH

Relation of the Algonkian (AL) slate and quartzite series to the Archean (AR) gneiss and schist, and the Cambrian (C) quartzite and shale

horizon is not represented by the Brigham quartzite and part of the overlying shale. That the shale beds of the great quartzite series below the unconformity have yielded no fossils after careful searching by many workers seems to argue against their Cambrian age. It is conceded by everyone who has seen them that the shales are well enough preserved to show good fossils, if any had been imbedded in them. There is, of course, still the possibility that fossils may yet be found in these lower shales, but the probability is not great. That the unconformity represents only a brief interval of time seems also to be incorrect from the manner in which it is disposed over the truncated edges of the lower series, as represented in the accompanying diagram, Fig. 3.

The variation of thickness of the Algonkian rocks might be accounted for in still another way. If they were laid down upon an irregular surface, filling up the valleys and thus reducing the relief, the surface upon which the Cambrian beds were laid down later might be relatively smooth and their uniform thickness would be accounted for, as well as the changeable thickness of the lower formations, but the relation of the beds above the unconformity to those below would be different. There would have to be practically no truncation of the lower members; the relation would be more nearly that of a disconformity, and the separation of the two series would be much more difficult on account of the lack of discordance. The advancing Lower Cambrian sea would rework the surface materials and a gradual transition would be established. Moreover, the close resemblance of the large rounded quartzitic bowlders in the conglomerate to the underlying quartzites is strong evidence that they were derived from them by stream erosion. This implies that the lower series was consolidated into hard sandstones before the invasion of the Cambrian sea, an inference which points to the much greater age of the lower quartzites. It seems, therefore, only possible to account for the great variation in thickness of the Algonkian rocks by erosion, before the deposition of the Lower Cambrian sediments upon their bevelled edges.

Relation of Algonkian to Archean

The relation of the Archean rocks to the Algonkian is not shown in the Cottonwood region. The base of the Algonkian series is not exposed. From its relation elsewhere, an unconformity doubtless exists and has been represented in the figure above given. The Archean oldland may have been devoid of relief but probably had some low monadnocks in places. If the Algonkian rocks are continental in origin, as is generally believed, the surface upon which they were deposited must have been relatively low and flat. The spreading fans and deltas of the Algonkian rivers slowly extended themselves and covered the surface of the Archean rocks. An unconformity, then, with overlap away from the source of supply, must separate these pre-Cambrian formations from the underlying Archean.

The highest member of the Algonkian in the Cottonwood region is a rock of somewhat unique characteristics. It is exposed at the head of South Fork and may be traced south into American Fork Canyon but soon disappears by overlap of the Cambrian beds. It has not been found in any other part of the range, but upon one of the islands of Great Salt Lake a rock of similar occurrence is found. The peculiar nature of the deposit consists of the extraordinary distribution of large and small bowlders within a rock which is otherwise fine enough to be classed as a shale or very fine sandstone. The unusual occurrence of the scattered bowlders of different sizes calls for a special explanation. Dr. Fred J. Pack[11] of the University of Utah has suggested a glacial origin for the bowlders that occur in a similar fine-grained black rock on Stansbury Island in Great Salt Lake. At that place, they show facetting suggesting ice erosion, though glacial striæ have not been seen. In the Cottonwood deposit, the bowlders are of greatly varying sizes, from small pebbles to blocks weighing several tons. The smaller ones show water action in that they are much rounded, but the extremely large ones are distinctly angular. It is difficult to imagine how such masses came to be imbedded in a rock which is otherwise so uniformly fine grained, unless we appeal to an agent like ice which has the power to carry them long distances and deposit them without changing their form to any marked extent. Ice-rafting might be suggested as a possible means for their irregular distribution. Facetting and more or less complete rounding of the smaller pebbles would also be conceivable on such an hypothesis. In fact, the heterogeneous nature of the deposit is one of the strong factors in support of the supposed glacial origin (see Plate II).

In the March number of the American Journal of Science for 1907, Coleman,[12] after a brief review of the reported occurrence of Paleozoic ice ages in many parts of the world, suggests the probable existence of a Lower Huronian ice age:

"For several years, it has seemed to me very probable that there was a still more ancient ice age, at the beginning of the Lower Huronian in the Archean as defined in Canada or the Archeozoic or lowest Algonkian as defined by various American geologists. The so-called Huronian 'slate conglomerate' of Ontario has attracted attention ever since Logan and Murray mapped and described it in the typical region north of Lake Huron nearly fifty years ago. Good descriptions of it are given by Logan in the 1863 report of the Canadian Geological Survey; where he refers to the different kinds of rock inclosed as pebbles or boulders, granite, felsite, certain green-stones and jaspers, for example; and describes the matrix as sometimes slaty, sometimes more quartzitic or like diorite or green-stone. At present the matrix would be called graywacke or slate though sometimes it is schistose or looks like an eruptive rock.

"The pebbles are in many cases subangular or sharply angular and are found miles away from any known source; and as they may be of any size up to blocks weighing tons, and are frequently very sparcely scattered through an unstratified matrix, a stone or two in several yards, one cannot help suspecting that the transporting agency was ice rather than water."

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[11] Personal communication.

[12] A. P. Coleman: "A Lower Huronian Ice Age," Am. Jour. Sci., Vol. 23, p. 187. 1907.

Coleman sums up the evidence for a Lower Huronian ice age as follows:

"A peculiar rock consisting of graywacke or finer material showing little or no stratification but containing pebbles or stones sometimes crowded but more often scattered a few feet apart, is found from point to point over an area 800 miles long by 250 miles broad. The stones are of all sizes up to diameters of several feet and of all shapes from rounded to angular, many being subangular with rounded corners. The stones are of several different kinds, some fragments of immediately underlying rock, others having a distant source.

"In the Cobalt region a few polished and striated stones have been broken out of the matrix. They are closely like the Pleistocene boulder clay of the same region except that they lack the Niagara limestones of the recent drift.

"Hand specimens of matrix and enclosed pebbles are precisely like the Dwyka tillite or conglomerate of South Africa which is undoubtedly of glacial origin."

It is obviously impossible to connect these deposits in eastern Canada with those of the Cottonwood area in Wasatch Mountains, without some surer means of correlation than lithological similarity. If, however, we accept Coleman's evidence, the occurrence of glaciation is probable over an area which is much too large to be attributed to local mountain glaciers. The two Utah occurrences are 60 miles apart and were undoubtedly of much wider distribution, having been removed by erosion previous to the deposition of the Cambrian beds, as previously explained. It is highly probable that these exceptional sediments are to be explained on the same basis, and that suggested by Coleman deserves serious attention and may be accepted at least for the present. An ice age of sufficient duration to manifest itself over such a large area in eastern Canada might easily be expected to register its effects in the western part of the same continent, especially at approximately the same latitude and northward.

Mr. E. L. Bruce, a member of the Canadian Geological Survey who has seen the rocks as they occur in Canada and also the writer's material, says that they are strikingly similar in almost every detail. The description quoted above from Coleman's article applies equally well to the black rock at the head of South Fork in Big Cottonwood Canyon. If we accept them as glacial deposits, they are probably of the same age, and the quartzite-slate series in the Wasatch and Uinta mountains is much older than has been thought up to the present time. From the obvious scientific importance of establishing the existence of an ice age in that early period of the earth's history, the question deserves further careful study.

Origin and Nature of the Algonkian Sediments

The nature of the Algonkian rocks has already been partly discussed and a very general description given in the sections by the Fortieth Parallel geologists and Dr. Walcott. These may be briefly summarized as follows: The prevailing rocks are quartzites and interbedded shales, the quartzites being mostly light colored, white and yellow to light brown; the shales, dark purple and green to black. Toward the top of the series, thin sheets of conglomerate occur in the quartzites, in which small well-rounded pebbles of quartz and quartzite are abundant. In a dark shale at the base of the series, mud cracks are abundant. To these characters may be added several others observed by the writer and also mentioned by Blackwelder. The quartzites are often prominently cross-bedded, the discordant angularity of the beds being usually of small amplitude. Ripple marks of the long parallel type are often common in the sandy shales. Limestones are totally absent, and though conditions favorable to the preservation of fossils seem to be abundant and right, no organic remains have been discovered.

From the intermediate geographical location of the Big Cottonwood section with respect to the Grand Canyon section on the south and the many occurrences of thick pre-Cambrian sediments to the north in Idaho and Montana, and from the fact that many of the above mentioned features of the Wasatch Algonkian have also been recorded from these other localities, it seems logical to suppose that they must have the same or a very similar origin. Upon whatever basis one is explained, the rest will probably also be explicable. Limestones and dolomites are met with in the northern and southern series and show that those regions had more varied conditions of sedimentation, involving periodic inundations of the sea, unless they are of fresh water origin. The major portions of the rocks are, however, clastic sediments and show physical characteristics which point to a continental origin. Shrinkage cracks and ripple marks in the shales and shaly sandstones indicate extensive mud flats comparable to the flood plains of many of our large rivers. Cross-bedding of the type here found suggests shifting water currents such as those of terrestrial rivers rather than wind. So that if we postulate a river origin for most of the quartzites and shales, we have at once a complete explanation of the physical characters already noted and the conspicuous dearth of fossils. Barrell[13] argues for the dominant flood plain origin of mud cracked

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[13] J. Barrell: "Geological Importance of Sedimentation," Jour. of Geol., Vol. XIV, pp. 553-568. 1906.

formations. Subaërial deposition in an arid region would also account for the highly oxidized character of most of the beds. While a final conclusion must be reserved for future more extended studies, the presumption from the facts at hand is in favor of a continental origin for all of the Wasatch Algonkian and a large part of the Arizona, Idaho and Montana occurrences.

We may now inquire into the probable situation of the Archean oldland from which these sediments were derived. It is clear from the general distribution of the Algonkian rocks above referred to in a north-south belt from Arizona, through Utah, Idaho and Montana into British Columbia, that the source must have been to the east or west. If we examine the sections to the eastward, we find that as we approach the north-south line of the Front Range, these pre-Cambrian quartzites thin away and disappear, and we have late Cambrian strata resting with unconformity upon Archean rocks. It appears then that here we have an area which was actively eroded during Proterozoic and most of Cambrian time and that did not become an area of deposition until late Cambrian time. From the general absence of Lower Cambrian formations in this region and their presence in the Wasatch Mountains and westward in Nevada, it is clear that the Cambrian sea came in from the west. This seems to indicate the absence of any considerable land mass to the west and reduces our source of supply to the eastern oldland. We may then consider the continental divide to be the Archean axis of the Front Range in Colorado and its northward extension into Canada, from which the rivers flowed to the east and to the west. Those draining the western slopes of this Archean elevation opened out upon lowlands in central and eastern Utah and to the north and south. Here subaërial deposition began in the formation of great fans spreading westward and becoming more or less confluent toward the north and the south.

CAMBRIAN STRATA

The base of the Cambrian strata is now drawn at the unconformity above described. The separation of the rocks from the much older Algonkian formations has reduced their thickness from 12,000 feet, as formerly estimated, to less than 1000 feet.

The lowest Cambrian formation is a conglomeratic quartzite 700 feet thick. No fossils have been found in it, and its age is fixed by its position above the well marked unconformity and below the succeeding shale bed carrying the *Olenellus* fauna. At the base lies a heavy conglomerate composed of rounded pebbles and bowlders of quartzite and gneiss and the black conglomerate already referred to as occurring at the head of South Fork. The conglomerate is nowhere of very great thickness, being usually less than 10 feet. Within the lower 200 feet of the succeeding quartzite are several sheets of fine conglomerate, the pebbles being quartz and quartzite. The remaining 500 feet are of coarse white quartzite which weathers to a light yellow or cream color. It is well bedded into layers varying from a few inches to several feet in thickness. Toward the top, the beds become uniformly thinner and gradually pass into shale, the latter being intercalated between the thin sheets of quartzite. Hanging from the under side of several quartzite layers in this transition zone are curious *Arthrophycus*-like structures. The sandy shale layers show well-preserved ripple marks of the parallel types, proving the shallow water origin of these sediments and their transitional character.

A similar quartzite formation is of wide occurrence in the Wasatch Range to the north and south and in the Basin ranges to the west. It is everywhere very similar in its appearance and physical characteristics and is followed by a dark shale of Lower or Middle Cambrian age. From its occurrence near Brigham City, Utah, Walcott has called it the Brigham quartzite, and though it is better shown at Willard and several other places along the range, we may retain the original name to avoid repetition. In Big Cottonwood Canyon, it is well exposed just below the old Maxfield mine and may be seen on both walls of the canyon. Southward, it becomes the east wall of Mineral Fork, underlying the limestone and shale which form the capping of Kessler's Peak. Dipping to the northeast, it cuts across the head of South Fork and crosses the divide into Little Cottonwood Canyon just north of Alta.

Overlying the Brigham quartzite, just at the Maxfield mine, is a dark micaceous, sandy shale, which, from its prominence just at the little town of Alta, we may call the Alta shale. It rests conformably on the Brigham quartzite with which it is in bold contrast on account of its black color. It is somewhat variable in thickness, ranging from 150 to 200 feet. From a sandy character near the base, it passes slowly into a thinly bedded, fine-grained shale in the middle and upper part, representing a continuous depositional unit. From two horizons within the Alta shale, 100 feet apart, Walcott[14] reports the following Middle and Lower Cambrian fauna from Big Cottonwood Canyon:

[14] C. D. Walcott: U. S. Geol. Surv. Bull. No. 81, p. 319. 1891.

Middle Cambrian.......	*Lingulella ella* *Kutorgina pannula* *Hyolithes billingsi* *Leperditia argenta* *Ptychoparia quadrans* *Bathyuriscus producta*
Lower Cambrian........	*Olenellus gilberti* *Cruziana* sp.

Dr. Walcott continues: "As in the Eureka and Highland Range sections, the *Olenellus* zone is confined to a very narrow belt just above the quartzite. The silico-argillaceous shales (Alta) above occupy the position of the 4650 feet of Prospect Mountain limestone and Secret Canyon shale of the Eureka section. The Hamburg limestone and Hamburg (Dunderburg) shale of the latter are absent in the Big Cottonwood section, causing an unconformity by non-deposition. The section in the Oquirrh range above Ophir City has a quartzite at the base with shales above it carrying *Lingulella ella*, *Olenellus gilberti* and *Bathyuriscus productus,* as determined by the collections brought in by the Wheeler survey. It is probable, however, that as in the case of the Big Cottonwood section, *Olenellus gilberti* occurs at the base of the shale, and the other two species at a higher horizon."

From this, it appears that the Middle Cambrian is only represented by the middle and upper part of the Alta shale, and the Upper Cambrian is wanting altogether. There exists, therefore, within the shale a disconformity between the Lower and Middle Cambrian strata and at the top a great hiatus representing the entire Upper Cambrian series.

ORDOVICIAN STRATA

Disconformably overlying the Alta shale is a limestone and shale series of which the following section, measured at the south end of the Reade and Benson ridge at the head of South Fork, is typical:

Section in South Fork

	Feet
13. Alternating blue shale and limestone conglomerate in beds 1–6 inches thick..	10
12. Alternating shale and limestone, passing into shale..................	20
11. Thin fissile blue shale..	6
10. Dark blue thin-bedded limestones, partings exceedingly irregular.....	55
9. Dark blue heavy bedded limestone with a wormy appearance, holes far apart..	45
8. White limestone, thin bedded..	10

		Feet
7.	Dark blue wormy looking limestone greatly resembling typical bird's-eye limestone of the east	85
6.	Thin-bedded brown shale, strongly jointed toward the top	60
5.	Finely intercalated lime and shale	10
4.	Light blue streaky limestone, weathers white	15
3.	Blue heavy bedded limestone with wormy appearance toward top	60
2.	Brown shale, blocky appearance from extreme jointing	75
1.	Blue limestone intercalated with seams of clay giving a banded appearance	30
	Total	481
	Subformation: Alta shale	200

No fossils were found in the beds of the above section, but the ramifying tubes in the "wormy" looking members are very suggestive of some form of life. Placed side by side, it is difficult to detect any appreciable difference between the specimens of the Ordovician Bird's-eye (Lowville) limestone of New York and those taken from this section. Within this part of the Wasatch, this character is a constant one and is a striking feature by which the rocks of this horizon can always be told. Though it has afforded no fossils within the area studied, it is interesting as representing the first limestone making period of this region. No coarse clastics occur, and the series belongs essentially to the off-shore facies, where conditions of sedimentation were constant for considerable lengths of time, but on the whole subject to quite frequent change. The period is brought to a close by a withdrawal of the sea and exposure of the surface to erosion. The limestones of this new land area were broken up and worn round, typically lens-shaped, and deposited in a curious helter-skelter fashion with many of the flat pebbles standing on edge. Hand specimens taken are almost identical in appearance with those described and illustrated by Blackwelder[15] from China. Intra-formational conglomerates from the Lower Ordovician have also been reported from Pennsylvania.[16] In the Lakeside Mountains, west of Great Salt Lake, there is a bed of similar limestone conglomerate of considerable thickness belonging to the Beekmantown horizon. While the age of the beds below the "edgewise" conglomerate of the above section cannot be told definitely because no fossils were found in them, they are referred provisionally to the Ordovician. They are of special interest because the largest ore deposits of the region have been found in them. The rich galena bedded vein of the Maxfield

[15] E. Blackwelder: Research in China, Vol. 1, Part 2, pp. 384-390.

[16] G. W. Stose: U. S. Geol. Surv. Folio 170. 1910.

T. C. Brown: "Notes on the Origin of Certain Paleozoic Sediments," etc., Jour. of Geol., Vol. XXI, pp. 232-250. 1913.

property at Argenta, in Big Cottonwood Canyon, is a good example, and from this occurrence the name Maxfield formation is suggested for the series.

SILURIAN STRATA

The presence of Silurian strata in western America was doubted for a long time. It has recently been shown by Kindle,[17] however, that the Silurian period is represented in a number of widely separated regions, and among them, in the northern Wasatch. In Green and Logan Canyons, east of Cache Valley, Cache County, Utah, Kindle reports the following fauna obtained by F. B. Weeks:

Favosites gothlandica Lamark
Favosites niagarensis Hall
Halysites catenulatus Linn.
Zaphrentis sp.
Pentamerus oblongus Sow.

Below the Paradise limestone which carries these forms, there is a dark colored limestone of undetermined age. Above it there is a dark magnesian limestone 800 to 1000 feet thick, carrying Devonian types. How far the Silurian strata extend toward the south is not known. Blackwelder reports limestones 1000 to 1500 feet thick in the northern Wasatch, on the west side of Cache Valley, which lie between the Geneva formation of Ordovician age and the identifiable part of the Mississippian. In the lower part of this limestone series occur *Halysites* and *Favosites,* and a brachiopod fauna somewhat higher up is thought by Kindle to be the same as his *Pentamerus* fauna of the Bear River range.

From the occurrence of these limestones at Ute Peak, near the southern end of Cache Valley, the Fortieth Parallel geologists gave the name Ute limestone to the Silurian strata of the Wasatch region. Special mention was made of the occurrence of this member at Alta, in Little Cottonwood Canyon, where a limestone 1000 feet thick is boldly exposed above the Cambrian shale on the north side of the canyon. Above this so-called Ute limestone, and separating it from the higher limestone series known as the Wasatch limestone, are nearly a thousand feet of quartzite and shale, mostly quartzite, which were called Ogden quartzite from their somewhat greater development in Ogden Canyon. The Ute limestone thus appears as a stratigraphic unit between two well-defined quartzite formations in its typical occurrence. In the latter part of this report, it

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[17] E. M. Kindle: "Silurian Fauna in Western America," Am. Jour. Sci., 4th Ser., Vol. 25. 1908.

is shown that the so-called Ogden quartzite is an overthrust block of partly Algonkian and Cambrian quartzite and shale, lying upon limestone of Devonian age. Blackwelder has recently shown that the same relation exists in Ogden Canyon and that the Ogden quartzite does not exist as originally defined. It now appears that the typical Ute limestone also has no existence as a regular depositional unit but is in reality the lower part of what was called the Wasatch limestone. The name Ute limestone, therefore, must go the way of the Ogden quartzite and be discarded. The Fortieth Parallel section is thus reduced over 3000 feet in thickness by the elimination of these two members. No name has yet come into general use for the Silurian strata of the northern Wasatch as they have been little studied, but the one employed by Blackwelder, *viz.*, Paradise limestone, might serve. In the central Wasatch, this is apparently wanting altogether.

The absence of Silurian strata in the central Wasatch may be due to non-deposition or to their complete removal by erosion. The only evidence of a great erosion interval in this part of the section is that already mentioned at the top of the Maxfield formation. Limestone conglomerates, however, are looked upon with suspicion as forming true basal beds since the discovery of the intra-formational types. Nevertheless, there is no reason why this could not be a basal conglomerate upon an old erosion surface, for limestones of Lower Ordovician age are of wide distribution in the west.

DEVONIAN STRATA

Below the lowest *Productus* horizon of the Mississippian in the Cottonwood region occurs a cherty limestone in which there are abundant corals of a few species. Fossils apparently from this horizon were reported by Professor Sanborn Tenny[18] of Williams College as early as 1873. He described the locality as follows:

> "In a position southeast of Great Salt Lake City on the divide between Great Cottonwood and Little Cottonwood, 9,000 feet to 10,000 feet above sea, is a dark blue limestone, containing corals."

The corals collected were two species of Zaphrentis and one of Syringopora, which R. P. Whitfield called *Syringopora maclurei* Billings but regarded as probably a new species. These were roughly referred to the Upper Helderberg horizon.

Little attention, apparently, has been given to the paper by Professor

[18] S. TENNY: "Devonian Fossils from the Wasatch Mountains, Utah," Am. Jour. Sci., 3rd Ser., Vol. 5. 1873.

Tenny, for Devonian strata have generally been held to be absent in this part of the range. Boutwell,[19] in his report on the Park City district, says that Devonian fossils have only been found in the northern part of the Wasatch range, and the formation in which they occur has been withdrawn from the Wasatch limestone and correlated with the Jefferson limestone.

Section in South Fork

(Upper continuation of the section given under the Ordovician)

	Feet
Pennsylvanian (Weber quartzite):	
30. Hard brownish sandstone	500
29. Limestone conglomerate	3 to 10
Unconformity.	
Mississippian (Reade formation):	
28. Cherty light yellow argillaceous limestone with large Zaphrentoid corals	5
27. Thin-bedded fossiliferous blue limestone	350
26. Brown and red shales	35
25. Cream colored sandstone	250
24. Massive blue limestone with productus	300
Devonian (Benson limestone):	
23. Hard dark blue cherty coralline limestone	100
22. Massive dark blue limestone	300
21. Fossiliferous blue limestone	3
20. Thick-bedded blue limestone	100
19. Dark blue cherty and brecciated limestone	200
18. Hard blue limestone	100
17. Dark porous limestone, very fossiliferous	21
16. Thick-bedded blue limestone, extensively bored	120
15. Thick-bedded light blue limestone	43
14. Thin-bedded blue limestone	45
Total	2,475

Disconformity.
Subformation: *Maxfield formation.*

Kindle[20] has described the Jefferson limestone fauna and traced the beds from their type locality in Montana southward into the Wasatch Mountains of northern Utah. The following section is given from Green Canyon:[21]

[19] J. M. Boutwell: U. S. Geol. Surv. Prof. Paper 77.
[20] E. M. Kindle: "The Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountains," Bull. Am. Pal., Vol. 4, No. 20.
[21] *Ibid.*, p. 16.

Section in Green Canyon

	Feet
D. Gray non-magnesian limestone, partly covered	900±
C. Dark gray to black magnesian limestone, generally with saccharoidal texture	1,100±
B. Thin-bedded limestone, buff or brownish near the top, with peculiar concretionary development with thin-bedded bluish-gray limestone in lower part	100
A. White to light gray magnesian limestone, with chert or siliceous beds locally developed	150
Total	2,250

Kindle correlates the dark magnesian limestone (C) with the Jefferson limestone of Montana. The following is a list of the species obtained from Green Canyon:

Productella spinulicosta
Camarotœchia sp.
Spirifer argentarius
Leiorhynchus utahensis sp. nov.
Spirifer disjunctus var. *animasensis*
Pterinopecten sp.
Actinopteria sp.
Cytherella sp.

In discussing the evidence of the fauna of the Jefferson limestone, Kindle has chosen three forms, *Spirifer utahensis, S. engelmanni* and *Martinia maia,* as the most abundant species represented, all of which are not reported from the northern Wasatch section. All of these, however, and seven other types common to the Jefferson are characteristic fossils of the Nevada limestone of Eureka, Nevada, with which it is correlated.

The Jefferson limestone has a known north-south extent of 425 miles, and from the thickness given for it in the northern Wasatch, it should be expected to continue southward a considerable distance. Aside from strata of close lithologic resemblance with the Jefferson reported by Blackwelder from the region northeast of Ogden, nothing is known of these beds south of Cache Valley. Eastward, they are not known beyond a line through central Montana and western Wyoming. From northern Colorado south to the southern part of New Mexico, the Ouray type of Devonian prevails, characterized by *Camarotœchia endlichi* and other Upper Devonian types. The east-west line which separates these two faunas appears to be the borderline between Colorado and Wyoming, latitude 41° N. Extended westward, this line intersects the Wasatch about midway between Ogden and Salt Lake City and includes the Eureka district of Nevada in the southern division. Since, however, the Nevada limestone fauna shows close affinity with the Jefferson rather than the Ouray, the line which separates the latter from the Jefferson and Nevada limestone faunas must curve to the south somewhere in Utah. It should be expected that these two distinct faunas representing different parts of the Devonian, the Jefferson, Lower and Middle, and the Ouray, Upper, will overlap somewhat, but thus far no section has been found where this condition is shown.

Ouray Type of Devonian in the Central Wasatch

It was with very great interest that the writer discovered *Camarotœchia endlichi* and a number of other typical Devonian forms in the Cottonwood region. On Montreal Hill, near the head of Mill D, South Fork, in Big Cottonwood Canyon, occur very fossiliferous light blue limestones, at the base of which the following forms were obtained:

Schuchertella chemungensis Hall
Orthoceras sp.
Spirifer orestes var. *wasatchensis* var. nov.
Spirifer sp.
Fenestella sp.
Rhynchonella sp.

Immediately overlying this horizon and ranging through about 250 feet of limestones occur the following forms:

Euomphalus utahensis Hall and Whitfield
E. luxus White
E. ophirensis H. and W.
Spirifer orestes var. *wasatchensis*

In a third richly fossiliferous horizon, in which *Spirifer orestes* var. *wasatchensis* and *Eunella linklœni* are the most abundant, practically making up the body of the limestone, occur the following:

Spirifer orestes var. *wasatchensis*
Eunella linklœni Hall
Cystodyctia gilberti Meek
Euomphalus cf. *cyclostomus*
Athyris coloradensis Girty, cf. *A. brittsi* Miller
Aviculopecten sp.
Camarotœchia sp.
Cryptonella ? *circulata* Walcott
Euomphalus ophirensis H. and W.

In an outcrop considerably higher up, stratigraphically, but almost completely covered so that it was somewhat doubtfully in place, two specimens of the following well-known Ouray limestone type were obtained:

Camarotœchia endlichi Meek

Of the above species, the ones having the widest range are *Euomphalus* and *Spirifer orestes* var. *wasatchensis*. *Euomphalus utahensis*, *E. laxus* and *E. ophirensis* have commonly been described as Mississippian from their resemblance to the Waverlyan species of the Mississippi Valley. Their association here with a Devonian fauna, and their range practically from the bottom to the top, indicates that they are probably older than Mississippian, though they may have persisted in other sections into the lower part of the Mississippian. It would otherwise be necessary to assume that the Devonian forms had survived till the Mississippian in order to explain this association, but this seems hardly warranted from the occurrence of *Eunella linklæni* Hall and *Cystodyctia gilberti* Meek which are described elsewhere as coming from the Middle Devonian (Lower Hamilton of Ohio).

In looking for the equivalent of this fauna in the West, that of the Ouray limestone in western Colorado suggests itself both from its proximity and its striking faunal resemblance. Kindle,[22] who has described the Ouray fauna and has done more than anyone else in suggesting a correlation of the western Devonian strata, has the following to say:

"*Camarotœchia endlichi* may be considered the most characteristic species of the Ouray fauna, for it has been found at practically every outcrop where the fauna has been recognized from northern Colorado to southern New Mexico."

The occurrence of this widespread species in the central Wasatch has brought the western border line of the Ouray fauna nearly 200 miles west of the western boundary of Colorado, which Kindle believed to mark its western limit. While the outcrop from which the Wasatch representatives were obtained was poorly exposed and their associates were not discovered, they may nevertheless be present in the Wasatch region, and later search should reveal them. The presence, however, of this most characteristic species is, it would seem, sufficient to indicate the equivalency of the two formations. Moreover, the resemblance of the faunas that were found below the *endlichi* horizon to the Upper Devonian fauna of Iowa points to an eastern connection rather than one with the Jefferson limestone of the West.

[22] E. M. Kindle: Bull. Am. Pal., Vol. 4, No. 20, p. 20. 1908.

The stratigraphic relations of these beds to the underlying non-fossiliferous limestones provisionally assigned to the Ordovician is one of disconformity. The beginning of Devonian sedimentation is very clearly marked by a limestone conglomerate which rests upon a thin bed of yellowish-green shale, which in turn rests on a thick limestone member. This condition is best shown on the Reade and Benson ridge, just above the old mine workings of the same name. It is also exposed on the ridge between Day's Fork and Little Cottonwood Canyon, just west of Flagstaff Mountain. No angular discord between the beds above and below the break could be detected, though the presence of the hiatus is physically indicated by the unmistakable conglomerate.

Upward, the Devonian strata seem to be continuous with the succeeding Waverlyan limestones. In this respect again, the central Wasatch is like the Colorado and New Mexico areas where deposition is thought to have proceeded continuously from the Upper Devonian into the Mississippian. From the occurrence of these limestone beds on the Reade and Benson ridge, the name Benson limestone is proposed to designate the part belonging to the Devonian. They range as above stated from Middle to Upper Devonian and are succeeded by Lower Mississippian limestones without any observed disconformity.

MISSISSIPPIAN STRATA

Rocks of Carboniferous age have been known from the Wasatch Mountains and the Great Basin region since the first explorations of Captain Stansbury in the early fifties. It was left, however, to the Fortieth Parallel geologists to give them a name and describe their stratigraphic relations, thickness and distribution. King applied the name Wasatch limestone to a succession of strata 7000 feet thick and composed mostly of limestones supposed to be of "sub-Carboniferous" age. Aside from the fact that this name was preoccupied for a Tertiary formation, it is now known that the original Wasatch consists of several stratigraphic members, ranging in age from Ordovician to Mississippian. In the northern Wasatch, the Paradise limestone of Silurian age and nearly a thousand feet of limestone identified by Kindle as the equivalent of the Jefferson have been separated from the lower part of the Wasatch. The rest has been regarded by Girty as Lower and Middle Mississippian, the lower division probably correlating with the Madison limestone. It seems advisable, therefore, to discontinue the use of the name Wasatch limestone as employed by King.

In the central Wasatch region, the Mississippian strata admit of a three-fold subdivision into a lower limestone series with a *Productus* fauna, a middle sandstone and shale, apparently barren of fossils, and an upper limestone series which is very fossiliferous. These beds are well exposed in Big Cottonwood Canyon at the northern end of the Reade and Benson ridge which separates South Fork from Day's Fork. At Green's Hill in South Fork, the lower limestone can be traced across the canyon from east to west. From the cliff which rises on the west, the following forms were obtained:

Productus semireticulatus
Productus cora
Derbya sp.
Hapsyphyllum sp.

The sandstone and shale which overlie this limestone member were not well exposed within the district, usually forming the bottom of gulches because of their poorer resisting qualities to weathering and being largely covered with talus and soil. No fossils were found in them, but they may have been overlooked because of poor exposures. The sandstone, where seen, is composed of much angular material giving it the aspect of a breccia. The prevailing color of the sandstone is light yellow, straw color, while the shale which overlies it has a reddish tint. It is an interesting fact that Blackwelder has noted a similar occurrence sixty miles to the north, in Ogden Canyon, and several localities thereabouts. The exposures there are apparently better and have been carefully described. Lavender and maroon shales with abundant sun-cracks filled with mud and sand and the same brecciated appearance are noted. From these and other characters, a continental origin is suggested, the necessary conditions being found on the surface of deltas of flat gradient in regions which are either generally or seasonably arid. The presence of this non-marine member within the Mississippian was not noted until it was discovered in Ogden Canyon by Blackwelder[23] in 1910, and its recognition in Big Cottonwood Canyon by the writer gives it a much wider distribution and importance as a stratigraphic unit. It will, no doubt, partly account for the limited development of the Mississippian rocks in the Wasatch Mountains. In this connection, the unconformity at the top of the over-lying thin-bedded limestones is of great importance. As will be shown, this represents a great interval of time during which much of the Upper Mississippian must have been removed by erosion. From the fossiliferous portion of the limestone immediately below this break, the following forms were obtained:

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[23] E. Blackwelder: "New Light on the Geology of Wasatch Mountains, Utah," Bull. G. S. A., Vol. 21, pp. 528-529. 1910.

Caninea cylindrica Scouler
Spirifer striatiformis Meek
Dielasma attenuatum Martin
Seminula subtilita
Spirifer rockymontanus
Productus semireticulatus
Phyllipsia cf. *trinucleata* Herrick
Amplexus sp.
Orbiculoidea newberryi
Spirifer sp. nov.

Caninea cylindrica is a well-known European species and so far as the writer is aware has not been recognized before in America. It is characteristic of the middle part of the Lower Carboniferous in Belgium and the region about Bristol, England. Probably next in importance is *Spirifer striatiformis* which is very abundant in the Cottonwood region. It likewise points to the Middle Mississippian.

By far, the most abundant form is the great coral *Caninea.* The individuals lie closely packed together in a layer about three feet thick, being very firmly cemented together with a siliceous clay which has become exceedingly hard. They were discovered by the writer in the early part of the season, and it was thought that they would make an easily recognizable reference horizon on account of their abundance and size, but while their general position was located in many places, no other occurrence was found.

Immediately overlying this coral bed is the basal Pennsylvanian conglomerate made up of rounded chert pebbles and silicified corals together with much fine material. This erosion surface truncates the lower beds, as may be inferred by the absence of the coral layer in all other places within the district except the one in which these interesting forms were first discovered near the mouth of South Fork. Careful observation seems to indicate some difference of dip between the upper quartzite beds and the lower limestones. The relation, therefore, is one of low angular unconformity.

Unconformity between the Mississippian and Pennsylvanian

There can be no doubt that there exists an unconformity at the top of the Mississippian in the Cottonwood section. The occurrence of a similar break farther to the north has also been reported by Blackwelder[24] at the base of the Morgan formation. He says: "The lower limit of the formation (Morgan) is sharp, for the earthy red sandstones rest upon

[24] *Op. cit.*, pp. 529-530.

a cavernous weathered surface of fossiliferous gray limestone. Just above the contact lies a coarse sandstone which consists of well-rounded frosted sand-grains bound in a deep red matrix and including bits of limestone and black chert from the underlying series. Although the bedding of the Morgan formation is essentially parallel to that of the limestone below, the relations here clearly indicate a disconformity, signifying an erosion epoch between the Mississippian and the Pennsylvanian." From faunas obtained above the disconformity, which show close relationships, the erosion interval is thought to be geologically brief in that region.

Dr. C. P. Berkey[25] has also described an unconformity at the base of the Weber quartzite in the western Uintas. He says in part:

"The base of the overlying formation, chiefly quartzite, is a true basal conglomerate. There are abundant fragments and pebbles and boulders from the cherty limestone bed immediately below, and in some places the finer cementing or filling matter is calcareous rock flour (calcilutite) and granular limestone (calcarenite) and chert (silicarenite). Fossils are abundant below the break but rare above it in this area. From the above, it is certain that there is an erosion disconformity in the Upper Carboniferous of the Uintas that marks moderate readjustment of levels, so that the strata are not perfectly conformable in angle, although the later folding of the range has been so much more profound that this is lost sight of except along the immediate break."

In the western Uintas, there are two strongly developed quartzites. Barring discrepancies in thickness and noting only succession, the uppermost one of these would appear to correspond to the true "Weber." The erosion break occurs here at its base. While Berkey puts the disconformity into the Upper Carboniferous, he establishes the fact that it occurs below the Weber quartzite, which corresponds exactly with its position in the Big Cottonwood section. Many of the details of description also correspond, such as the prevalence of cherty pebbles and much fine material and slight discordance of dip between the upper and lower layers. An absence of fossils above the break in these two sections is also significant. In the northern Wasatch sections at the base of the Morgan formation, fossils occur in limestone layers, showing, according to Dr. Girty, that the unconformity there corresponds to a brief time interval. To decide the value of the unconformity, it is only necessary to find a section not too remote which shows no break and compare it with the Wasatch sections and Berkey's western Uinta section. Such a one is to be had at Mercur in the Oquirrh Mountains.

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[25] C. P. Berkey: "Stratigraphy of the Uinta Mountains, Utah," Bull. G. S. A., Vol. 16, pp. 524-527. 1905.

Mercur Section

In Lewiston Canyon, at the head of which is the little mining town of Mercur, there is exposed a great anticlinal fold, the axis of which runs northwest and southeast, somewhat diagonal to the general trend of the range, which is north-south. Lewiston Canyon cuts directly across the fold, exposing the anticline on both sides of the canyon. The lowest rocks brought up are of Lower Carboniferous age, and the highest exposed, directly over the axis of the fold, are also of that age. The crest of the range to the east rises on the east limb or flank of this anticline, and here are exposed the rocks of Upper Carboniferous age. The section thus exposed is as follows:

	Feet
4. Upper intercalated series	5,000–6,000
3. Great blue limestone	5,000
2. Lower intercalated series	600
1. Lower blue limestone	200

Above the Upper Intercalated series comes the great Weber quartzite 8000 feet thick exposed on the eastern slopes of the Oquirrhs at Bingham and northward. Below the Lower Blue limestone, in Dry Canyon, which parallels Lewiston Canyon on the north, are several hundred feet of Lower Carboniferous limestone, below which come 2000 feet of Devonian, Silurian, Ordovician and Cambrian strata. There is thus a great series of sediment exposed in these three localities ranging from the Cambrian to the Upper Carboniferous.

Fossils obtained from the Lower Blue limestone by Mr. Spurr,[26] and examined by Professor Schuchert, were found to be of Mississippian age. The limestone is a dark blue, semi-crystalline rock, in which zaphrentoid corals seem to be the most abundant fossils.

Above the Lower Blue comes the Lower Intercalated series, 600 feet thick, the lowest member of which is a sandstone 100 feet thick. Above this come frequent alternations of siliceous and calcareous sediments (silicilutytes and calcarenytes). Two parallel sections measured on the steep bare walls of the canyon three-fourths of a mile apart showed considerable thinning of these beds toward the east, even in this slight distance.

Above these intercalated beds is a great limestone succession 5000 feet thick, broken only in two places by very dark calcareous shales, one about a thousand feet below the top and the other about the same distance from

[26] J. E. Spurr: "Geology of Mercur District, Utah," U. S. Geol. Surv., 16th Ann. Rept., Part II, pp. 371-377. 1894.

the bottom. From the lower shale, a bryozoan and brachiopod fauna was obtained, which Professor Schuchert assigned to the Burlington-Keokuk horizon. The upper limit of the Great Blue limestone merges gradually into the Upper Intercalated series, which, with its frequent alternations of siliceous and calcareous beds, is in sharp contrast with the heavy blue layers of the Great Blue limestone. Between these two formations, Schuchert places the division between the Carboniferous and Mississippian. The Mississippian in the Oquirrhs is thus made somewhat over 6000 feet, and the upper division, counting the Weber quartzite exposed at Bingham and over a large area to the north, between 15,000 and 18,000 feet.

To facilitate the discussion and bring out the relationships which exist among the Carboniferous formations of the Oquirrh, Wasatch and Uinta mountains, columnar sections from these three ranges taken in an approximate east-west line through the Cottonwood district have been drawn side by side in Fig. 4. The distance between Mercur and Big Cottonwood Canyon is about equal to the distance from Big Cottonwood to the western Uintas, being in the neighborhood of thirty-five miles.

The much greater development of Mississippian and Pennsylvania strata in the Oquirrh Mountains is seen at a glance. The corresponding parts are indicated by the dotted lines. It becomes apparent at once that the unconformities shown in the Wasatch and Uinta sections represent a long interval of erosion. Farther to the east, in Colorado, this same unconformity has been reported between the Mississippian and Pennsylvanian formations, and the same explanation no doubt applies there as well. It seems reasonable to suppose that the Mississippian was represented by much thicker formations in these sections at the beginning of Pennsylvanian time than is shown at present. The Great Blue limestone was very probably represented in them all, but just when the area of the Wasatch and eastward into Colorado was lifted and exposed to erosion cannot be definitely stated. It was probably toward the end of Great Blue time. During the long period of erosion which followed, most of the Mississippian limestone was worn away and transported elsewhere to be deposited as calcareous mud or, if dissolved, remain in solution in the sea water. The new shore line receded westward until it came to occupy some position between the Wasatch and Oquirrh mountains. Here it seems to have remained for a long time, as we may judge from the nature of the great deposits which formed in the Oquirrh Mountain area.

Above the Great Blue limestone, we have the Upper Intercalated series, which on the Mercur side of the divide is from 5000 to 6000 feet thick, but it continues east of the divide and may be as much as 10,000 feet in

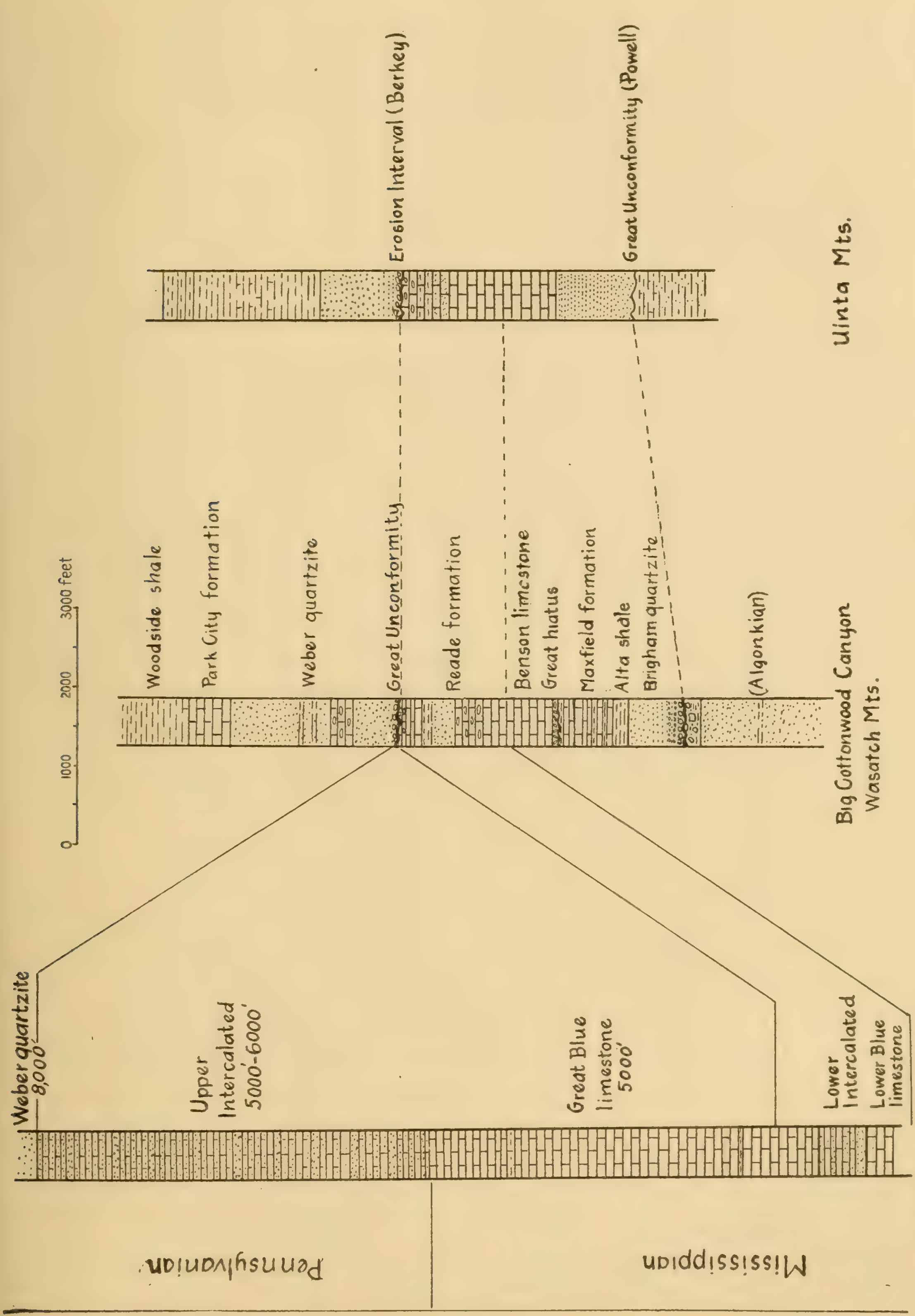

FIG. 4. SECTIONS TO SHOW THE GREAT UNCONFORMITY BETWEEN THE MISSISSIPPIAN AND PENNSYLVANIAN IN THE WASATCH AND UINTA MOUNTAINS, AND ITS VALUE IN THE OQUIRRH MOUNTAINS

thickness before the Weber quartzite is reached. This series is described as consisting of numerous alternations of sandstones and sandy limestones. many of the beds presenting for considerable distances complete intermediate stages between the more calcareous on the one hand and the more arenaceous on the other. The presence of marine fossils throughout the series, in the more calcareous layers, may be taken as good proof that the deposit was formed in the sea and probably not far from the shore. The lime muds from the great limestone area toward the east became mingled with the sands of the shore, giving rise to the calcareous sandstones which are so prominent a part of these intercalated beds. The Mercur report leaves much to be desired in the matter of details concerning the organic record. With the excellent exposures to be had there and the obvious importance of knowing what fossils are imbedded in these rocks, it is to be hoped that this section will soon receive the careful study which it deserves. Enough has been done, however, to determine the age of the series as a whole, and to warrant the comparison that is here made. Following Spurr's report, we may assume that deposition was continuous in the Oquirrh Mountains. The hiatus, therefore, in the Wasatch and Uinta sections, represents a long erosion interval, comparable in time to the period necessary for the deposition of the 6,000 to 10,000 feet of intercalated limestones and sandstones. It seems also probable that it was even much longer, as will be brought out in the discussion of the Weber quartzite problem (see Fig. 4).

PENNSYLVANIAN STRATA

Weber Quartzite

Following the basal Pennsylvanian conglomerate in the Big Cottonwood section is a quartzite 1000 feet thick, in which no fossils were found. The sand grains are of fairly uniform size, giving a rock of even, rather fine-grained texture. The bedding is prominent and regular in layers of moderate thickness. While the surface has a brownish appearance, the freshly broken rock is quite colorless. Ripple marks, cross-bedding and other shallow water characters seem singularly wanting, yet the fine detrital nature of the deposit certainly points to shallow water deposition. In the upper portion, thin limestone layers are intercalated between the sandy beds, and a succession of mainly cherty blue and white limestones follow, making up several hundred feet in thickness. These are well exposed on the north side of the canyon, just opposite the government forest station. Above these limestone beds, the quartzites reappear and give another thousand feet of fine-grained white rock. The series thus defined above the disconformity which terminates the Mississippian strata constitutes what is here called Weber quartzite. In the Park City district to the east, Boutwell[27] reports only the upper portion of the Weber quartzite as seen in outcrops.

> "The middle and basal portions of the formation, which are not present in this area, outcrop in prominent cliffs just south of the district. Except for a few thin limestone beds near its top, the middle portion is massive quartzite, but in the lower part, the intercalated limestone members increase in number and thickness."

The middle and basal portions here mentioned correspond with part of the upper and middle parts of what is called Weber quartzite in this report. The thickness given in Boutwell's section is 1350 feet, which he regards as too small and gives a tentative estimate of 3500 feet. The exact thickness is still doubtful, as continuous exposures could not be found within the Cottonwood district, but 3500 feet is probably too great. Somewhat more than 2000 feet is thought to be more nearly correct.

In the type locality in Weber Canyon, 30 miles to the north, the Fortieth Parallel geologists[28] have given the thickness as 5000 to 6000 feet. This figure has been questioned by Blackwelder,[29] who follows Weeks[30] and separates the lower red beds of that section from the Weber and calls them the Morgan formation. There is, however, no doubt that the development of the Weber quartzite in Weber Canyon is considerably greater than in Big Cottonwood and that the thickness is subject to variation from place to place. In less than 15 miles north of Weber Canyon, it disappears altogether and the Park City limestone which overlies the Weber in all of the southern sections rests directly on Mississippian limestone. Blackwelder describes the unconformity as one of low angular discordance, the beds of early Mississippian age being slowly truncated, over the edges of which the Park City limestone rests. As we go southward, the Morgan formation and Weber quartzite appear between the Mississippian limestone and Park City formation. The Park City beds thus overlap the Weber quartzite and Morgan red beds, and going still lower rest on early Mississippian.

It is also important to note that in Weber Canyon, the Morgan formation rests on much higher Mississippian beds than in the northern sections. This fact may be explained in several ways. The presence of a

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[27] J. M. Boutwell: U. S. Geol. Surv. Prof. Paper 77, p. 45.
[28] C. King: U. S. Geol. Expl. 40th Par., Vol. I, p. 161.
[29] E. Blackwelder: *Op. cit.*, p. 531.
[30] F. B. Weeks: Unpublished report of U. S. Geol. Surv., quoted by Blackwelder. 1908.

widespread unconformity between the Pennsylvanian and Mississippian throughout Colorado, Wyoming, northern Arizona and all of Utah, with variable amounts of the Mississippian strata present in the different sections, may explain the absence of the Upper Mississippian strata in Blackwelder's northern sections. That this was a long period of erosion has already been explained, and the disappearance of the Weber northward may well be by natural thinning due to overlap. The position of the Weber quartzite in the Oquirrh Mountains above the intercalated beds, which are not represented in the Wasatch sections and those farther to the east, indicates that the hiatus at the base of the Morgan formation in Weber Canyon represents a considerable interval of time. The Morgan formation is considered to be of very local extent and may be taken to be a part of the Weber.

The relation of the Weber to the overlying Park City formation is described in the early reports as one of complete conformity. In the Big Cottonwood section, the division line is covered in most places and was not studied in detail by the writer. The section given by Boutwell[31] in the report on the Park City district, as the type section for that area, was measured in Big Cottonwood Canyon, on the ridge east of Mule Hollow. This section was verified by the writer and may be taken as representative for the upper divisions of the Weber quartzite and higher formations. Of the contact in question, the Park City report reads as follows:

"No unconformity was observed with the underlying Weber quartzite, or the overlying shale, or within the formation (Park City). Accordingly, it would seem that sedimentation proceeded unbroken from Mississippian time through that part of Pennsylvanian which is represented by the Park City formation."

Blackwelder[32] on the other hand concludes from his studies in Weber Canyon that there is an unconformity. He says:

"The Weber quartzite is limited above by an irregular eroded surface, which is not exactly parallel to the bedding; it was subject to disintegration; and not merely one, but a variety of beds in the formation were exposed, as is shown by the large amount of chert as well as quartzite in the breccia. On the whole, the evidence for the existence of an unconformity at this horizon seems to be conclusive.

"The importance of the unconformity is uncertain. If the Weber quartzite is a formation of only local extent, and if some of the more calcareous beds farther north were deposited contemporaneously, then the observed unconformity may in fact be due to a slight erosion of the surface of the formation

[31] *Op. cit.*, p. 51.
[32] *Op. cit.*, p. 533.

and should represent but a brief land interval. If, however, the Weber quartzite was once far more extensive than now, and if it has been removed from the northern part of the Wasatch region, and elsewhere reduced to a varying thickness by erosion within the Pennsylvanian period, then the interval must have been relatively long. It is significant in this connection, that the fragments of quartzite in the basal breccia were quartzite, rather than sandstone, when broken from the parent ledge, during the erosion interval, as is shown by the preservation of sharp corners and edges."

The exact amount of time represented, if we grant the presence of an unconformity between the Weber quartzite and the Park City formation, can only be decided by finding out the ages of these two members. If the Park City formation is Pennsylvanian in age and the Weber quartzite is late Pennsylvanian, as the Oquirrh mountain sections indicate, then the interval must be short and relatively unimportant and cannot explain the great variation in thickness of the Weber and its total disappearance in sections not far distant from its type locality. If, on the other hand, the Park City formation is made Permian in age and the Weber quartzite early Pennsylvanian, then a great hiatus must exist between the two formations. Such a one should be well marked, and we should expect it to be especially easy to recognize where the Weber is thinnest by its most extensive erosion. The presence of a basal conglomerate with well-rounded quartzite pebbles should be expected within short distances of the present occurrences of the parent body. Again, if the Park City formation is Permian in age and the Weber late Pennsylvanian, a small hiatus may exist between the two, such as has been described by Blackwelder. It may be safely assumed that the Park City beds are late Pennsylvanian or early Permian, and in view of the high position of the Weber quartzite in the Oquirrh mountain sections, it seems clear that no great erosion interval exists between these two formations. The thinning of the Weber is more easily accounted for by overlap, as it was undoubtedly laid down on a surface that had been long exposed to erosion.

PARK CITY AND LATER FORMATIONS

The Park City formation has been named from the Park City mining district within which it carries bonanza ore bodies. No good exposures are known, however, from the Park City area, and within the area specially studied for this report, the formation does not occur. It is of interest, nevertheless, to give the characters of this formation some consideration from the widespread occurrence of this member in the central Wasatch and northward.

The Park City formation lies between the Weber quartzite and the red beds of the Woodside shale, and, in the type locality on the north side of Big Cottonwood Canyon, it has a thickness of about 600 feet. As exposed there, it consists largely of limestone with intercalations of sandstone and quartzite. Its differentiation below from the Weber quartzite is readily made by the appearance of calcareous layers which soon give way to a thick bed of limestone. As before stated, in the central Wasatch this transition indicates continuous deposition from Weber into Park City time. The occurrence of limestones nearly as extensive as those of the Park City formation within the typical Weber is well known, and this suggests that the Park City beds mark the recurrence of one of these periods of limestone formation when typical marine conditions prevailed.

In the older reports, the upper coal measure limestones represent this horizon. They were especially noted for the abundant fauna which they carry and have usually been regarded as of Carboniferous age. Of late, however, some tendency is shown to place them higher in the series, possibly in the Permian. In the correlation table here given, the interpretation of the various workers is placed at the right and that of the writer on the left. This view is supported by the fauna and stratigraphic relations which are better shown in Dry Canyon, to the north, than in Big Cottonwood Canyon. There is in that section between 500 and 600 feet of red shales and brownish sandstones between the Meekoceras beds of the Lower Triassic and the upper fossiliferous portion of the Park City formation. These seem to rest with low angular unconformity upon the Park City beds and carry an abundance of a single species of *Lingula* in the beds next to the contact. Faulting is frequent in this area, and the apparent discrepancy in dip between the two sets of beds may be due to that cause, but a search failed to reveal evidence of faulting. From the nature of the beds of red shale and brownish sandstones, it might be expected that they should bear a relation of unconformity, or at least disconformity, to the typical marine beds upon which they rest. From the widespread occurrence of Permian red beds in the west, these are thought to be of that age. The fauna of the upper part of the Park City formation indicates their Carboniferous age. Prominent forms are:

Productus multistriatus
Productus subcostatus
Spiriferina pulchra
Spirifer cameratus
Lingulodiscina utahensis
Athyris (Seminula) argentea
(Rhynchonella) Pugnax swallowiana

In Red Butte Canyon, the next gulch to the south of Dry Canyon, occurs a heavy conglomerate and a considerable thickness of purple sandstone. These purple beds were called Permian by the geologists of the Fortieth Parallel Survey. Overlying them are the strongly cross-bedded red sandstones which form the prominent red cliff at the mouth of the canyon, from which it has derived its name. These are the "Triassic red beds" of Hague and Emmons. The discovery of the *Meekoceras* fauna several hundred feet below the purple sandstones has carried the lower limit of the Triassic down below what was called Permian into those beds which were mapped as upper coal measures by the Fortieth Parallel geologists. The simple synclinal structure for this region shown on the Great Basin sheet of that survey is now also known to be more complicated, including at least one large anticline and another syncline to the south of Emigration Canyon. The new geologic map of this region now being prepared by Mr. N. C. Christensen and Dr. F. J. Pack will look very different from the present one, and it is expected that the separation of the Jurassic, Triassic, Permian and Carboniferous can be definitely accomplished in this region. For the present, the interpretation here given (page 126) is thought to be very near the true one.

TENTATIVE CORRELATION TABLE

Period		Central Wasatch	Northern Wasatch	Wasatch Range
			Weeks, Kindle, Blackwelder and Walcott	Hague and Emmons (40th par.)
Jurassic		Nugget sandstone	(absent)	Jurassic
Triassic		Ankareh shale Thanes formation	(absent)	Triassic Red Beds
Permian		Woodside shale	(absent)	
Pennsylvanian		Park City formation Weber quartzite (absent)	Park City formation Weber quartzite Morgan formation	Upper Coal Measure limestone Weber quartzite
Mississippian		Reade formation	Madison limestone	Wasatch limestone (Ogden quartzite and Ute limestone eliminated)
Devonian		Benson limestone	Jefferson limestone	
Silurian		(absent)	Paradise limestone	
Ordovician		Maxfield formation (unfossiliferous limestones and shales)	Geneva formation Boxelder limestone	
Cambrian	Upper	(absent)	St. Charles formation	Primordial slates and quartzites (Big Cottonwood series)
	Middle	(absent) Alta shale	Nounan formation Bloomington formation Blacksmith formation Ute formation Langston formation	
	Lower	Quartzite and shale	Brigham quartzite	
Algonkian		Big Cottonwood quartzite and shale series	Quartzites and shales near Huntsville	
Archean		Gneiss and schist	Gneiss and schist	Archean gneiss and schist

Structure

INTRODUCTORY STATEMENT

The first unified account of the larger structural features of the Wasatch Mountains is that given by the geologists of the Fortieth Parallel Survey.[33] In a broad way, these early observations have been verified by the more recent studies of particular parts of the range, but many important new facts have been added and some of the original conceptions greatly changed.

Vital to the first conception of Wasatch structure was the supposed presence of an Archean axis which had the same trend as the present range, north and south, on the flanks of which were deposited the early Paleozoic sediments, until they completely buried the lofty Archean peaks. At the close of Mesozoic time, profound plicating and plateau forming movements threw the thick conformable Paleozoic and Mesozoic sediments into great pitching anticlinal and synclinal folds with axes mainly north and south. After a period of erosion during which the upper parts of the folds were planed off, profound faulting along the present western faces of the range took place, tilting the old surface eastward on the uplifted eastern side. Upon that uplifted block, erosion has carved the present relief.

It is now known that the main body of supposed Archean, the Little Cottonwood granite, is intrusive, and the original conception of a pre-Cambrian protaxis has been entirely discarded. Folding is known to be much more intense than originally thought, and large overthrusts have been discovered from Ogden northward to Willard and in the Cottonwood district.

Since the overthrusting, there has been considerable deformation and faulting which have introduced the most complicated tectonic relationships.

STRUCTURE OF THE CENTRAL WASATCH

The central Wasatch is an exception, structurally, from the general anticlinal aspect of the range as a whole. Within this area, extensive intrusion of granite and granodiorite and widespread extrusion of andesitic lava, with their accompanying phenomena of metamorphism, are grandly displayed. Encircling the main intrusive body, the Little Cottonwood granite, are steeply inclined quartzites, shales and limestones, with varying age ranging from pre-Cambrian to late Mesozoic. Dipping

[33] U. S. Geol. Expl. 40th Par., Vol. II, Sect. 3 & 4.

quaquaversally from the nucleus of granite, this great series of sediments forms the eastern half of a huge dome abruptly cut off on the west by a profound fault. The western half was depressed and is now entirely covered by the deep accumulation of rock waste forming the floor of the Salt Lake Valley. Eastward, the Carboniferous and Triassic formations are breached by an irregular stock of fine-grained granodiorite which culminates in Clayton Peak. Beyond this line of elevation, which forms the present divide, an extensive flow of andesite was poured out in an elongated synclinal depression that separates the Wasatch from the western Uintas. It is significant that the anticlinal fold of the Uinta range is in line with the eastward prolongation of this domed arch and that they are connected beneath the igneous covering by the Kamas prairie syncline.

Little Cottonwood Granite

The structural relation of the Little Cottonwood granite to the sediments which flank it upon all sides has been variously interpreted. By the geologists of the Fortieth Parallel, the contact was described as one of sedimentary unconformity; and the granite was thought to be older than the quartzites that appear to overlap it. The absence of a basal conglomerate was noted, and the whole situation was thought to be extraordinary. At that time, the intrusive occurrence of granite had not been conceived, and the indications of contact and regional metamorphism escaped notice, so that while the evidence of a sedimentary contact was not in accord with conditions commonly regarded as necessary, the relation was still held to be due to sedimentation.

In 1880, Geikie[34] visited this region and later published his conclusions. He found structural evidence that led him to regard the granite as intrusive, and probably post-Carboniferous in age, rather than pre-Cambrian as given by the Fortieth Parallel geologists.

In 1900, Boutwell visited Little Cottonwood Canyon and examined the contact of the granite and quartzite on the ridge south of Twin Peaks. Here he found dikes of granite extending up into the quartzite and sills of granite leading off laterally from the dikes. Inclusions of quartzite in the granite were also observed, and the intrusive nature of the granite was thus established. These results were verified by Emmons[35] who later published his conclusions regarding the granite as in-

[34] A. Geikie: "Archean Rocks of Wasatch Mountains," Am. Jour. Sci., 3rd Ser., Vol. 19, pp. 363-367. 1880.

[35] S. F. Emmons: "Little Cottonwood Granite Body of the Wasatch Mountains," Am. Jour. Sci., 4th Ser., Vol. 16, pp. 139-147. 1903.

trusive and pre-Jurassic in age and the chief folding of the sediments as Jurassic.

The Little Cottonwood granite has commonly been regarded as laccolithic in structure, since its intrusive character has been known. While the inclosing quartzites do dip away in all directions from the central igneous mass, suggesting that they may have been arched up by the intrusion, the essentials of laccolithic structure are nowhere shown. The far-reaching metamorphic effects of the granite upon the contiguous sediments, its uneven ragged contact on all sides and its thorough crystalline coarse texture all indicate a mass of irregular shape and great size. It would seem advisable, therefore, to speak of the Little Cottonwood mass as a stock and reserve the term laccolith for the more special type of intrusive.

As to the geologic data of the intrusion, there is also much uncertainty. The latest sediments cut are Algonkian, and possibly Lower Huronian, in age. If the mass were known to be laccolithic, then the latest sediments affected by the arching would give the desired information; or, if the doming of the strata is due to the intrusion of the granitic stock, then the age might quite easily be stated as later than the youngest beds that are involved. But it is difficult in this region of strong folding to distinguish between the flexing due to regional folding and that due to a special cause such as intrusion, where the two come so close together.

A few general considerations may lead to a closer approximation of the date of the intrusion than can be made from the sediments cut by it. The Little Cottonwood granite mass lies in an east-west zone of eruption which has been active in some parts in post-Triassic, probably Tertiary time. At Bingham, it is marked by a large body of post-Carboniferous monzonite and trachytic extrusion. Still farther west, the sheets and dikes of the Mercur and Ophir districts are in the westward continuation of this belt. Just east of Alta is a large irregular stock of granodiorite which cuts Carboniferous limestones and adjoining it to the east is the Clayton Peak mass of quartz diorite which cuts Triassic strata. The interrelations of these three main intrusive bodies have not been discovered in the field. They are not in surface connection with each other, so far as known, but a northeast-southwest system of dikes and veins is characteristic of the whole region; and closely associated with the ore bodies. These dikes are clearly later than the folding, since they do not show deformation and from their similarity to the larger intrusive masses they may be assumed to have come from them, though none has actually been traced to the junction point. They are seen to disappear beneath rock debris within a few hundred feet of the larger bodies, however, and are surely connected with them. If such a contact could be seen, it would shed much light upon the relative ages, but in the absence of actual proof, we may only reason about them.

If we assume that the Little Cottonwood granite, the Alta granodiorite and the Clayton Peak quartz diorite are connected below, as is commonly done, they are probably not of very different ages and may be taken as being as young as the most recent sediments cut. This would make them post-Triassic. If the fracturing of the beds and intrusion of the dikes came after the folding, which is thought to be late Cretaceous, and if this occurred contemporaneously with the intrusion of the larger bodies, as might be the case, then the Little Cottonwood granite, as well as most of the other igneous masses, are post-Cretaceous.

The extrusive andesites of the Kamas prairie to the east are in contact with the Vermillion Creek beds of the Eocene as reported by the Fortieth Parallel geologists.[36] They are thus later than these early Eocene beds and represent the latest igneous activity of the region. Their relation to the porphyritic dikes and granitoid intrusives of the Cottonwoods is not known, but they are probably much later. The Little Cottonwood granite was no doubt uncovered during the period of erosion which followed the post-Cretaceous folding. The extrusions came after the upturned Paleozoic and Mesozoic beds had been strongly truncated, covering the old surface in the depression between the Wasatch and Uinta mountains.

The date of the intrusion of the granite will presently be further discussed when the problem of overthrusting and faulting near Alta is taken up. From the above, it appears that the granite probably came in immediately preceding or possibly accompanying the folding in post-Cretaceous time. The eruptive andesites are post-Vermillion Creek and belong undoubtedly to the Tertiary period.

STRUCTURE NEAR ALTA

In the Alta region, the most obvious structure is an eastward dipping monocline, which to the north and south slowly curves westward, in accordance with the general dome structure for this part of the range. The strata stand at a considerable inclination, averaging between 35 and 45 degrees, but locally the dip may be much more and in some parts notably less. This simple structure is much complicated in places by folding and faulting. The folds are confined to a zone within the sedimentary series, the formations above and below having the ordinary monoclinal attitude. This condition has been brought about by over-

[36] S. F. Emmons: U. S. Geol. Expl. 40th Par., Vol. I, pp. 586-587. 1878.

thrusting, the weaker members in the lower part of the overthrust mass having been rolled together in such a way as to make it almost hopeless to try to make out any regular structures. Small Z-shaped folds have resulted in several places, and in others, overturned and isoclinal folding may be observed. North and south of Alta where the disturbance seems to have been the greatest, the weak shales of the Cambrian system have been drawn out into long tongues in the midst of the quartzites, entirely isolated from the limestones which normally overlie them. The dynamics by which this was accomplished in a region so complicated can hardly be explained. The strata plainly show that they have been torn loose from their normal position in the sedimentary series and involved in the zone of shearing so as to be widely separated from their former position.

In Big Cottonwood Canyon, above the Alta black shale exposed near the old Maxfield mine, rises a great series of limestones. Below the shale is a thickness of about 1200 to 1500 feet of Cambrian quartzite, and below that the Algonkian quartzite slate series 11,000 feet thick forms the base of the section. There is thus in Big Cottonwood Canyon a great limestone series overlying the Alta shale. These may both be traced southeast across the canyon where the limestones are seen to form the top of Kessler's Peak. Still farther along the strike, they cross South Fork and are best seen as the chief rocks making up the Reade and Benson ridge, on the east wall of South Fork. They may be continuously followed south into Little Cottonwood Canyon where they form the ore-bearing zone north of Alta. The Cambrian black shale can be traced along in the same way and some of the underlying quartzite, but just below Alta a second lower series of limestones outcrops in bold cliffs on both sides of the canyon, facing Superior and Peruvian gulches. To one familiar with the Big Cottonwood succession where no limestones appear below the Cambrian rocks, this condition at once suggests an overthrust. An examination of the rocks below the lower limestone revealed the Cambrian black shale as the first member and the familiar Lower Cambrian quartzites and the upper part of the Algonkian quartzite and slate series as the downward continuous succession. Below the upper limestones, which were traced over from Big Cottonwood, are, in order going down, the Cambrian black shale (Alta), the Lower Cambrian quartzite (Brigham) and the upper part of the Algonkian series which rests upon the lower limestones. There is thus a complete duplication of the strata from the upper part of the Algonkian through the Cambrian and including the lower 1000 feet of limestone of Ordovician and Devonian age. The evidence for overthrusting is therefore conclusive from a stratigraphic viewpoint. It seems strange that the Fortieth Parallel geologists should have overlooked this relationship. They seem to have been prejudiced from the similar relations which they had observed in the range to the north, in Weber and Ogden Canyons. In describing the Big Cottonwood section, King[37] has the following to say:

"Next above the Cambrian lie 1,000 feet of Ute limestone, which for the most part is very light colored, highly crystalline and characterized by peculiar cloudings of color that extend across the beds near the bottom of the series, and at one or two horizons near the top it is noticeable for containing a large proportion of tremolite, and under the microscope it is seen to be highly siliceous, the silica appearing as rounded glass grains of pellucid quartz. The outcrop extends up the hills on both sides of the canyon and to the south is conspicuous upon the divide, from which it descends into Little Cottonwood and in the valley a little way below Alta exposes a fine precipitous cliff, the result of a fault (the Superior fault of this report). Here again are seen the same highly crystalline, almost marble-like condition and the same prevalence of tremolite and silica. Under these circumstances it is not at all remarkable that the beds contain no fossils, but it is unquestionably Silurian, as will be seen later.

"Above the limestone occurs the white granular body of Ogden quartzite, which is here reduced in thickness to about 800 feet. It may be traced up the hill to the south and forms an interesting saddle in the ridge top, between the Ute limestone and the bold masses of Wasatch limestone which directly overlie it. Here are but limited traces of the thin body of greenish argillites that farther south, in the region of Rock Creek, were found on both sides as bounding-beds to the Ogden body."

The presence of the "Ogden" quartzite between the "Ute" and "Wasatch" limestones in the Big Cottonwood section seems to have been inferred from its prominent appearance on the ridge above Alta. In Big Cottonwood Canyon, no such quartzite member is exposed. The outcrop at the head of South Fork, having the described position between the two limestone members, can be traced northward along the strike of the beds into Big Cottonwood Canyon, where it appears below the lowest limestones there exposed. It therefore clearly belongs to the Cambrian. This fact might easily have been discovered had the early geologists attempted to explain the presence of a black shale above the "Ogden" quartzite on the ridge above Alta. For some reason this important horizon marker was overlooked or disregarded altogether. The "limited traces" above referred to are hard to harmonize with the good exposure of this Cambrian shale at the south end of the Reade and Benson ridge, where it shows its typical thickness, between 150 and 200 feet. The lower occurrence, below the "Ute" limestone, seems to have been noted, though the

[37] C. King: U. S. Geol. Expl. 40th Par., Vol. I, Sys. Geol., pp. 167-168. 1878.

thickness and exposure there are hardly more favorable for observation. The strong contrast between the black shale and the almost white quartzite makes the presence of the shale easy to recognize and renders it one of the best guides to the surface geology of the region (see Plate III, A).

Alta Overthrust

As already stated above, there is complete stratigraphic evidence of a large overthrust in the vicinity of Alta, for which the name Alta overthrust is proposed. It has been traced north from the locality where it was first discovered northwest of Alta into Big Cottonwood Canyon and south into American Fork. There can be little doubt, however, that it extends much farther in both directions. The dip of the overthrust beds is not very different from that of the strata upon which they rest, so that the attitude of the beds above the thrust surface furnished no clue to the relationship. The strong contrast in color and lithologic characters between the various stratigraphic members soon led to the recognition of a complete duplication of beds. The other factors were then soon discovered. Evidence of intense dynamic action was found in the highly folded and contorted conditions of the weaker strata. Rapid variation in the thickness of the beds, and the complete disappearance of some of them above and below the thrust surface were noted.

The accompanying diagram (Fig. 5) shows the relation of the beds above and below the thrust surface as they occur between Alta and Argenta, a distance of about four miles. The succession at the right is the same as that seen in the photograph (Plate IV, A). As we go northwest, the lower members of the series above the thrust line T T^1, as well as the limestones and shale below it, disappear, so that when Argenta is reached these beds are missing. The Cambrian quartzite has apparently become much thicker, being nearly twice as thick as it is in the two exposures near Alta and at the head of South Fork. The only duplication of strata shown in Big Cottonwood is the Cambrian quartzite, and that shows itself in the increased thickness of the beds, the exact line of separation not having been observed. On the north slopes of Kessler's Peak coming around from Mineral Fork, the thrust surface disappears beneath a heavy mantle of débris, and where it emerges on the north slopes of Big Cottonwood, it has not been found again.

From Alta southward, the thrust surface is more easily traced. The lower limestones outcrop all along the east wall of Peruvian Gulch to the Bullion Divide, where they cross over in a low saddle and form the floor of the great cirque at the head of American Fork, known as Mineral Flat. The lowest overthrust member is quartzite, plainly seen as the capping of Bald Mountain directly south of Alta (see geologic map, Plate VI). All along Peruvian Gulch and in American Fork, this seems to lie conformably upon the limestone. Both the limestone and the quartzite being very resistant, the contact is often sharp with very little crumpling or brecciation. The truncation of the beds, however, shows beyond any doubt the secondary nature of the structure. More-

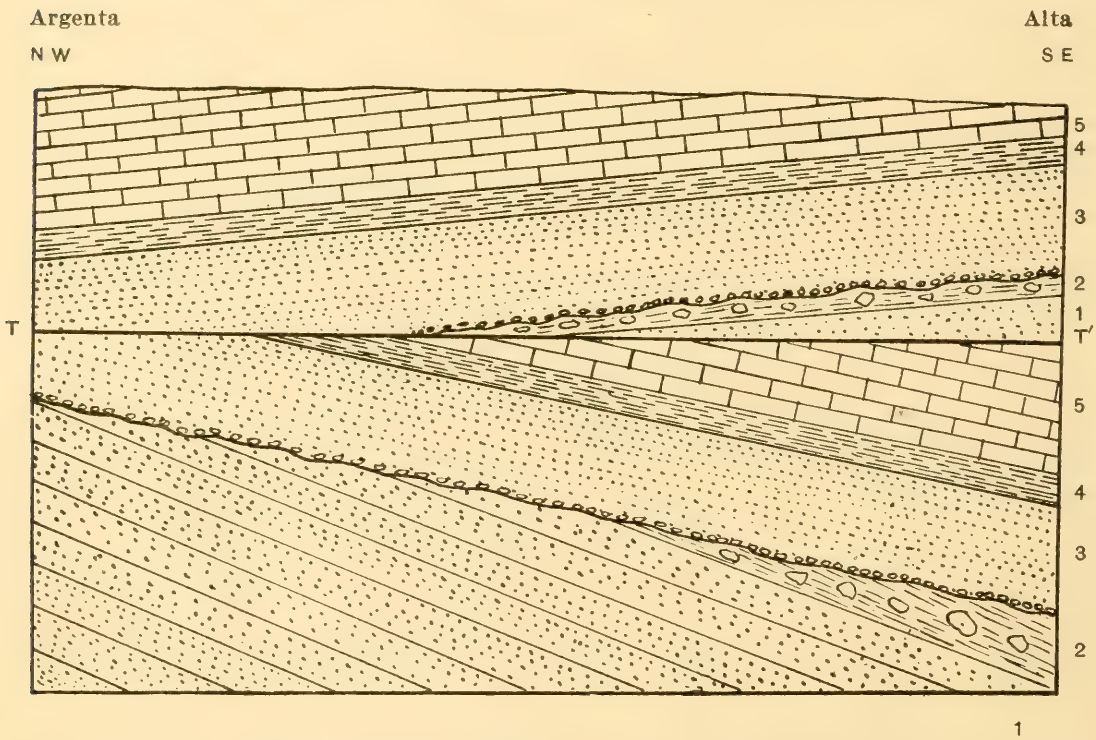

FIG. 5. SECTION BETWEEN ARGENTA, IN BIG COTTONWOOD CANYON, AND ALTA, IN LITTLE COTTONWOOD

Relation of the overthrust Paleozoic and Proterozoic strata to beds of the same ages below

1 = Algonkian quartzite. 2 = Algonkian "conglomerate." 3 = Cambrian quartzite 4 = Cambrian shale. 5 = Ordovician and Devonian limestones. TT′ = Thrust surface

over, in many places crumpling and brecciation have occurred—as should be expected. In all such cases, the limestones have been the least affected, but the overthrust quartzites and shales have suffered strong deformation. The best example of this condition is seen on the slopes northwest of Alta. The black Cambrian shale has here been drawn out into a long tongue in the midst of the quartzite, showing every inclination from strongly overturned folds near the Columbus mine to a vertical position farther up the hill. The quartzite is folded and smashed in such a way as to be chaotic, individual blocks being traceable for short distances only.

In the mine workings on this hill, the discontinuity of the beds seen on the surface is also shown. No regular structure can be followed very far within the quartzite, or overthrust zone. The deeper workings which drift far to the westward finally enter the limestones below the thrust mass, and here the dip is regular to the east. The thrust contact dips strongly to the east on the surface, but deeper it gradually flattens out.

The age of the overthrust is not positively known, but there can be little doubt that it occurred during, or at least at the close of one of the periods of folding in late Mesozoic time. The folding of the Wasatch is generally assigned to the close of the Cretaceous, but King[38] has described an unconformable contact between the local Dakota beds and the Jurassic and older sediments exposed along Mountain Dell road in the upper part of Parley's Canyon. The difference in dip of the beds is given as about 30 degrees, and the Cretaceous strata rest on the truncated edges of all of the older Mesozoic and Paleozoic formations, but elsewhere the Cretaceous is described as conformable with the older series, and this relation is the commonly accepted one. More work will have to be done to settle this question. If there was important folding at the close of the Jurassic, the overthrust in the Cottonwood region could have occurred then. It certainly took place before the intrusive action occurred in this district, as is evidenced by the independent manner in which the dikes cut through the basal series and overthrust blocks. This event followed or accompanied a period of northeast-southwest fracturing and faulting which preceded the period of mineralization. Still later, important faulting transverse to this first fracture line occurred, of which the Superior fault is the best known example. The overthrusting, therefore, appears to have happened along with or following the first dynamic disturbance in the region. Later warping has deformed the thrust surface and tilted the masses at a high angle.

Farther north in the range, Blackwelder[39] has described similar structures which he thinks were made at the same time that the Paleozoic rocks were folded, which is generally assigned to the close of the Cretaceous period, but he says "It seems to be a fact that the Lower Eocene (Wasatch) sediments cover the outcrop of the overthrusts in several places, thus indicating that the folded and overthrust structures had been deeply eroded." It is quite likely that these two districts less than fifty miles apart suffered overthrusting at the same time and that whatever period is deduced for one will be found to be the same for the other.

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[38] C. KING: U. S. Geol. Expl. 40th Par., Vol. I, p. 304.

[39] E. BLACKWELDER: "New Light on the Geology of Wasatch Mountains," Bull. G. S. A., Vol. 21, p. 539.

From southeastern Idaho and northern Utah, Richards and Mansfield[40] have described a great overthrust which involves strata of late Cretaceous age. The oldest rocks which have been found concealing its trace are the early Eocene conglomerate of the Almy formation,[41] making the possible range of age from late Cretaceous to early Eocene. This agrees closely with Blackwelder's determination for the Willard overthrust near Ogden, Utah.

The latest beds involved in the Alta overthrust are Pennsylvanian within the area studied, but from the general fact that overthrusting accompanies or follows strong folding, the overthrusts of the central Wasatch must belong to the late Mesozoic and are probably of the same age as the great Willard and Bannock thrusts.

The trace of the Alta overthrust has a trend north-northwest, while the thrust surface dips strongly to the east with the general monoclinal structure of the region. This leads to the belief that the movement was from east to west, though this is only tentative. The overthrust block seems to be continuous for eight or ten miles to the east, where it disappears below the quaternary beds of Kamas and Weber valleys. More extended work will be needed, however, to show definitely that the direction of thrusting is as above indicated.

Blackwelder thinks the overthrusting near Ogden came from the east, but Richards and Mansfield have questioned the correctness of this determination, as they believe it came from the west. There is thus a difference of opinion in a region perhaps better adapted to the determination of this question. It might be said, however, that the unsymmetrical anticlines of the Cottonwood region are steepest on the west, and in one or two cases seem to be overturned in that direction, suggesting strong lateral pressure from the east.

The structural relations along the trace of the Alta overthrust are shown in the structure sections accompanying the geologic map.

A Minor Overthrust

Immediately south of the town of Alta there is a mass of limestone, shale and quartzite which stands nearly vertical, dipping slightly to the west. In Collins's Gulch, the strata dip eastward at an angle of about 25 degrees. Across the ridge to the east of the Albion tunnel, the quartzites appear again with an eastern dip. There is thus between Collins's Gulch and the great cirque south of Alta, a mass of limestone, shale and quartzite

[40] R. W. Richards and G. R. Mansfield: "The Bannock Overthrust," Jour. of Geol., Vol. 20, No. 8. 1912.

[41] U. S. Geol. Surv. Prof. Paper No. 56, p. 89.

which is overturned and does not match with the lower beds on either side. All attempts to explain the structure as a syncline, or overturned anticline, fail when the succession of beds is noted, leaving the only reasonable basis of explanation that of an overthrust block.

Faults

In a region of such complicated structure, faulting may be expected to occur. Dislocations are met with in every mine, but those on a big scale are few in number. Whether large or small, they appear to belong to two systems of fracturing, but movement has probably occurred more than once in each system. The directions of these two sets of fractures are respectively north-east and south-west for those carrying the ores and dikes, and northwest-southeast. These correspond to the dip and strike of the Alta monocline and may therefore be classified as dip faults and strike faults.

The earliest displacements are those in which the fissure veins carrying the ore were found. These have a fairly constant direction, N. 70° E., and no doubt belong to the same period of fracturing which gave rise to the lode deposits of the Park City district which lie in the path of their northeastward extension. Into some of these, the dikes which are common in the southern part of the district were injected, and it is thought that the ore-bearing solutions came up in others at the same time, or immediately following, depositing the ores. The displacements above this first set of fractures do not appear to have been very great. They are probably more in the nature of great cracks which were formed through the effects of intrusion of the larger bodies of igneous rock to the east and west, as inferred from the correspondence of their direction with the general trend of the intrusives. On the other hand, when compared with the general dome structure of the region they are radial and might be considered as tension cracks made when the region was thrown into its present arched condition.

After the formation of the ore deposits of the district in the northeast-southwest fissures, a second period of faulting occurred, having a transverse direction to the first set of fractures. This is shown in the northwest-southeast faults encountered in many of the mines, where they invariably displace the ore bodies. A notable case is the great Atwood "slip" which cut out the ore of the famous Emma mine. Many other examples are known in the various mining properties.

The displacements of these strike faults are much greater than those of the earlier fractures. The one occurring in Superior Gulch running north into South Fork appears to have the greatest throw and has been called the Superior fault. A second one of great size cuts across the ridge from the head of Silver Fork into the Alta basin. It is seen most clearly on the ridge northeast of the Emma mine, where the fault breccia has weathered into relief, standing up like a great wall. This fault will be described as the Silver Fork fault. In all of these movements, the displacements are more in the vertical direction, lateral shifting being not so frequently met with.

Superior fault.—The Superior fault as shown upon the map (Plate VI) can be traced from the mouth of Superior Gulch in Little Cottonwood Canyon northward into South Fork. On the top of the ridge, it is clearly marked by a wall of breccia which stands up ten feet above the general level of the surface. The crushed zone marked by the breccia may be followed northward for nearly a mile. In the upper tunnel of the Cardiff mine, it is well shown for a distance of a thousand feet along which the hanging wall is quartzite and the foot wall very hard limestone.

From all indications in South Fork, where it was first encountered, it may be explained as a normal fault with a throw of about a thousand feet, but observations from the Alta side of the divide clearly show it to be a reverse fault of less magnitude, the displacement being about 600 feet. The limestones on the west are lifted. They belong to the lower series exposed on the east wall of Superior Gulch and not to the limestones of the Reade and Benson ridge as at first supposed. This was not understood until the overthrusting which duplicated part of the series was discovered at Alta. The limestones are all of the same age but they occur in two series separated by nearly a thousand feet of older quartzite belonging to the overthrust member. The faulting is clearly of later date than the overthrusting. The understanding of this relationship is of the utmost importance to the mining people of South Fork, who have never suspected the presence of a limestone series below the quartzites of the Reade and Benson ridge. The cherty limestones forming the ridge south of the Cardiff office and boarding house are the lifted, westward extension of that lower series upon which the overthrust block rests. The relation is clearly brought out in Section A-A, Plate VI (see also Plate III).

The direction of this movement is more nearly vertical than horizontal though the oblique flutings on the walls in the Cardiff tunnel indicate an important horizontal component toward the north on the west side. Surface evidence of faulting cannot be traced farther than the Cardiff mine to the northward, though it is safe to assume that a movement so pronounced at this last observation point must have continued for some distance beyond. At a point about a mile and a quarter north of the Cardiff, the bottom of South Fork is composed of limestone, and no evidence of faulting could be found; but on the north wall of Big Cottonwood Canyon opposite South Fork, faulting is clearly shown. Here the west block has gone down instead of up. If this fault has anything to do with the Superior fault, it must be in the nature of a pivotal fault with the fulcrum somewhere between the Cardiff mine and the mouth of South Fork.

Silver Fork fault.—At the head of Silver Fork of Big Cottonwood Canyon, on the ridge north of Alta, there is a wall of limestone breccia which stands up from 10 to 20 feet above the crest of the ridge, having a direction nearly north and south. On both sides of it are limestones, but their metamorphic condition prevents close observation as to the stratigraphic displacement because of the difficulty of identifying a suitable datum plane on both sides. Farther to the south in the gulch leading from Alta to the City Rocks and Alta Consolidated mines, the quartzite and shale of Cambrian age are faulted up on the east so that they are in contact with the limestones which normally overlie them. The displacement is estimated to be between 500 and 600 feet, though the exact amount of movement could not be readily determined. It is, however, a fault of considerable magnitude. The fault surface seems to be vertical, and it is therefore impossible to say whether it is of the normal or the reversed type. Minor parallel faults may easily be detected to the west along the top of Emma Hill and Flagstaff Mountain, but on account of the strongly metamorphosed condition of the limestones, the throws have not been determined. They are, however, thought to be only slight. It might be said by way of generalization that the block between the Superior and Silver Fork faults has gone down and that the west end appears to have been most depressed. The parallel fractures between them, therefore, may show that the west side has gone down in most cases. This, however, is merely a suggestion and may not be true in all cases.

Minor faults.—In the various mines of Alta, minor faults are known to be of frequent occurrence. They conform generally to the main directions of fracturing already referred to as northeast-southwest and southeast-northwest. The latter are invariably found to be younger than the northeast-southwest series of faults. The Columbus Extension tunnel has been driven northwest for a considerable distance along one of these breaks. Near the mouth of the tunnel, a displacement of 90 feet has been observed, but farther to the north it is probably less. On the divide between South Fork and Alta, a fault with a throw of about 30 feet is clearly shown on the surface. The west side has been depressed. This fault is shown in the structure sections B–B[1] and C–C[1] on the map.

South of the Columbus Extension, in the Alta Hecla property, several of these north-south vertical faults are to be seen underground. Prospecting along them has failed to develop ore except where the northeast-southwest fissures have been crossed. In every case, these ore-bearing fissures are offset, showing them to be older. The amount of shifting has only been worked out in the one case above cited, as far as known, but generally the displacements are not very great, except in the two large faults already described.

Summary of Conclusions

PHYSIOGRAPHY

(*a*) The central Wasatch is a maturely dissected block mountain, preserving in a modified condition the form of its original profile.

(*b*) Before the Wasatch fault was formed, the folded Wasatch formations were planed off by erosion, and several plutonic igneous masses were uncovered, notably the Little Cottonwood granite, the Alta granodiorite and the Clayton Peak quartz diorite stocks.

(*c*) Block-faulting in Tertiary time gave rise to the Great Basin ranges, and at the same time the Wasatch block was uplifted. When newly formed, it had a steep western face and a long gentle eastern back slope.

(*d*) The original crest line was the upper edge of the great fault escarpment on the west. This was also the original divide.

(*e*) The divide has migrated from its first position near the western margin to its present position near the eastern margin of the block. The present long west-flowing streams of such canyons as Big and Little Cottonwood are chiefly obsequent streams, being consequent near their mouths.

(*f*) The crest line has moved in the same direction as the divide, but only a short distance.

(*g*) The Provo and Weber Rivers are probably also obsequent streams in their canyons across the Wasatch. Their head-waters are the eastern consequents that have been captured, so far as the drainage of the Wasatch is concerned.

(*h*) The mature dissection of the Wasatch by stream action was accomplished before the Pleistocene. Upon the stream-cut topography certain features were superposed due to glaciation during the Pleistocene. Later modifications have been slight.

STRATIGRAPHY

(*i*) The major part of the great quartzite and slate series exposed in Big Cottonwood Canyon is Algonkian and possibly Lower Huronian in age.

(*j*) The Lower Cambrian is separated from the Algonkian by a heavy basal conglomerate of widespread occurrence. The Cambrian strata of the central Wasatch belong to the lower and middle divisions of the Cambrian system and are less than one thousand feet thick.

(*k*) Above the known Cambrian are about 500 feet of unfossiliferous limestones and calcareous shales provisionally referred to the Ordovician. Silurian strata are entirely wanting in the Cottonwood region.

(*l*) Middle and Upper Devonian horizons are represented by what appears to be an unbroken succession of limestones carrying faunas closely allied to those found in western Colorado and Iowa.

(*m*) The Devonian beds rest with disconformity upon the lower limestones and are separated from them by a thin bed of conglomerate composed of limestone pebbles.

(*n*) The Mississippian follows the Devonian conformably and is represented by limestones of Lower and Middle Mississippian age which are separated by a continental formation.

(*o*) In the Cottonwood region, there is an unconformity between the Mississippian and the Pennsylvanian (Weber quartzite) which follows, representing a considerable erosion interval. The thinning of the Weber quartzite is probably to be accounted for by overlap upon this erosion surface.

(*p*) The Wasatch limestone of the Fortieth Parallel geologists embraces strata of Ordovician, Devonian and Mississippian ages. The Ogden quartzite and Ute limestone of supposed Devonian and Silurian ages respectively have no existence, as originally defined, in the central Wasatch.

STRUCTURE

(*q*) In the vicinity of Alta there is a great overthrust, presumably from east to west; the overthrust block consists of beds ranging in age from Algonkian through the Paleozoic and Mesozoic; the underthrust member consists of Devonian and older beds.

(*r*) The age of the overthrust is probably the same as the main foldings of the Wasatch, generally assigned to the end of the Cretaceous.

(*s*) After the overthrusting occurred, there followed a period of intrusion in which large irregular granitic and dioritic masses together with numerous dikes were injected into the Mesozoic and older formations.

(*t*) North-south faulting near Alta has resulted in the formation of two master faults and numerous minor fractures. These run roughly parallel to the main Wasatch fault line and probably belong to the same period of readjustment.

Bibliography

PHYSIOGRAPHY

Atwood, W. W.: Glaciation of the Uinta and Wasatch Mountains, Utah. U. S. Geol. Surv. Prof. Pap. No. 61. 1909.

Davis, W. M.: Ranges of the Great Basin: Physiographic Evidence of Faulting. Sci., Vol. XIV, pp. 457–459. 1901.

Emmons, S. F.: Rept. U. S. Geol. Surv. 40th Par. Descr. Geol., Vol. II. 1877.

Geikie, A.: Ancient Glaciers of the Rocky Mountains. Am. Nat., Vol. 15, p. 3. 1881.

Gilbert, G. K.: Geographical and Geological Explorations and Surveys West of the 100th Meridian, Vol. III, pp. 17–187. Washington, 1875.

———: Lake Bonneville. U. S. Geol. Surv. Monograph I.

Johnson, D. W.: Block Mountains in New Mexico. Am. Geol., Vol. XXX, pp. 135–139. 1903.

King, Clarence: Rept. U. S. Geol. Surv. 40th Par. Sys. Geol., Vol. I. 1878.

Le Conte, Joseph: Origin of Normal Faults and of the Structure of the Basin Region. Am. Jour. Sci., 3rd Ser., Vol. XXXVIII, p. 257. 1889.

Russell, I. C.: Geological History of Lake Lahontan. U. S. Geol. Surv. Monograph XI. 1885.

Spurr, J. E.: Origin and Structure of the Basin Ranges. Bull. Geol. Soc. Am., Vol. 12, pp. 217–270. 1901.

STRATIGRAPHY AND PALEONTOLOGY

Berkey, C. P.: Stratigraphy of the Uinta Mountains. Bull. Geol. Soc. Am., Vol. 16, pp. 517–530. 1905.

Blackwelder, E.: New Light on the Geology of the Wasatch Mountains. Bull. Geol. Soc. Am., Vol. 17, pp. 517–533. 1910.

———: Handbuch der Regionalen Geologie, Vol. 8, Pt. 2, p. 136. Heidelberg, 1912.

Boutwell, J. M.: Geology and Ore Deposits of the Park City District, Utah. U. S. Geol. Surv., Prof. Pap. No. 77, pp. 41–65. 1912.

Emmons, S. F.: Rept. U. S. Geol. Expl. 40th Par., Vol. 2, p. 342. 1877.

Girty, G. H.: Carboniferous Formations and Faunas of Colorado. U. S. Geol. Surv. Prof. Pap. No. 16. 1903.

KINDLE, E. M.: Silurian Faunas of Western America. Am. Jour. Sci., Vol. 25, pp. 127–128. 1908.

———: Devonian Fauna of the Jefferson Limestone. Bull. Am. Pal., Vol. 4, No. 20. 1908.

KING, CLARENCE: Rept. U. S. Geol. Expl. 40th Par. Sys. Geol., Vol. 1. 1878.

PEALE, A. C.: U. S. Geol. Surv. of Mont., Ida., Wyo. and Utah (Hayden), pp. 105–108. 1872.

TENNY, S.: Devonian Fossils in the Wasatch Mountains. Am. Jour. Sci., 3rd Ser., Vol. 5, pp. 139–140. 1873.

WALCOTT, C. D.: Second Contribution to the Studies on the Cambrian Faunas of North America. U. S. Geol. Surv., Bull. No. 30. 1886.

———: Cor. Pap., Cambrian. U. S. Geol. Surv. Bull. No. 81. 1891.

———: Cambian Sections of the Cordilleran Area. Smith Misc. Coll., Vol. 53, No. 5. 1908.

STRUCTURE

BLACKWELDER, E.: New Light on the Geology of the Wasatch Mountains, Utah. Bull. Geol. Soc. Am., Vol. 17, pp. 533–542. 1910.

BOUTWELL, J. M.: Geology and Ore Deposits of the Park City District, Utah. U. S. Geol. Surv. Prof. Pap. No. 77, p. 43. 1912.

DANA, J. D.: Rocky Mountain Protaxis and post-Cretaceous Mountain Making Along Its Course. Am. Jour. Sci., 3rd Ser., Vol. 40, p. 187. 1890.

EMMONS, S. F.: Rept. U. S. Geol. Expl. 40th Par., Vol. 2. 1877.

———: The Wasatch Mountains and the Geologic Panorama of the Wasatch Range. Comp. Rend., Int. Geol. Cong., 5th Ses. 1891.

———: Little Cottonwood Granite Body of the Wasatch Mountains. Am. Jour. Sci., 4th Ser., Vol. 16, pp. 139–147. 1903.

GEIKIE, A.: Archean Rocks of the Wasatch Mountains. Am. Jour. Sci., 3rd Ser., Vol. 19, pp. 363–367. 1880.

GILBERT, G. K.: The Wasatch, a Growing Mountain. Bull. Wash. Phil. Soc., Vol. 2, p. 195.

———: A Theory of Earthquakes of the Great Basin. Am. Jour. Sci., 3rd Ser., Vol. 27, pp. 49–53. 1884.

HILLS, R. C.: Orographic and Structural Features of the Rocky Mountain Geology. Proc. Col. Sci. Soc., Vol. 3, pp. 362–388, 400. 1891.

KING, CLARENCE: Rept. U. S. Geol. Expl. 40th Par. Sys. Geol., Vol. 1. 1878.

RICHARDS, R. W. and MANSFIELD, G. R.: The Bannock Overthrust: A Major Fault in Southeastern Idaho and Northeastern Utah. Jour. Geol., Vol. XX, No. 8, pp. 681–709. 1912.

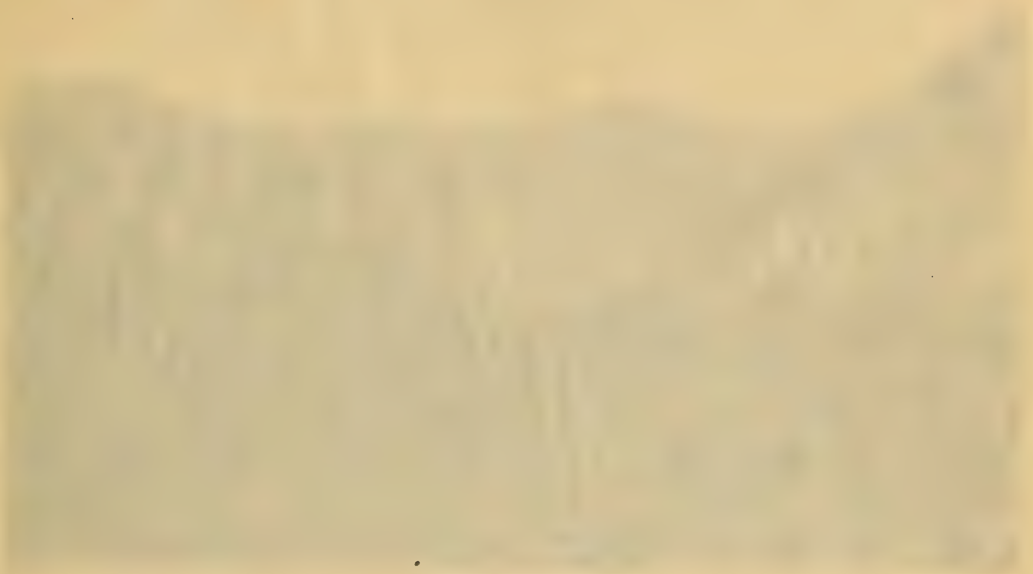
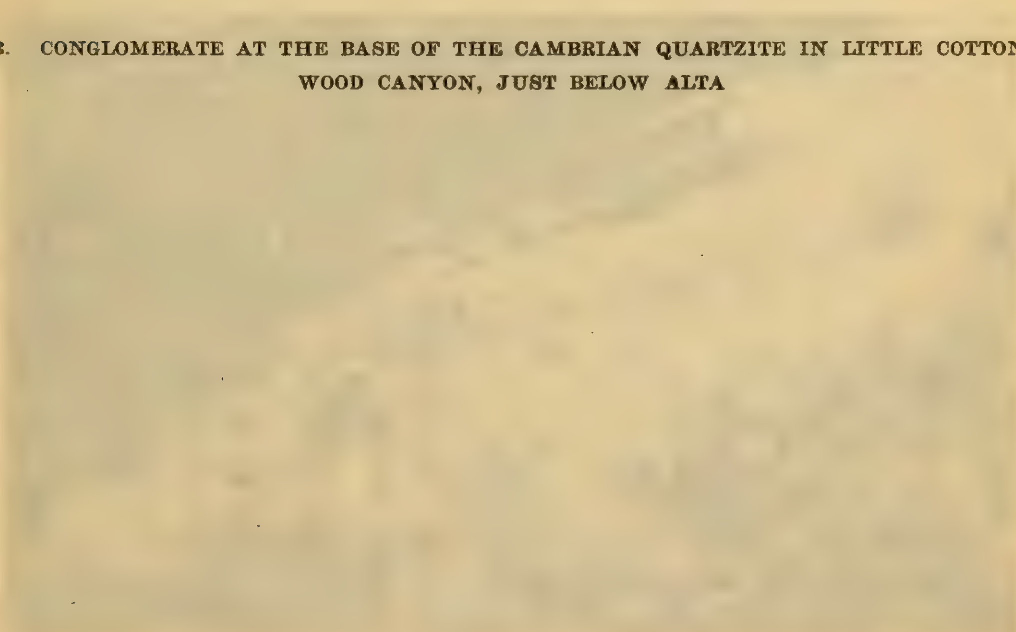


PLATE I

A. LOWER HALF OF SOUTH FORK OPPOSITE MILL D. BIG COTTONWOOD CANYON, LOOKING NORTH

Shows broad U-shaped glacial trough, with terminal moraine at the junction of the main canyon

B. CONGLOMERATE AT THE BASE OF THE CAMBRIAN QUARTZITE IN LITTLE COTTONWOOD CANYON, JUST BELOW ALTA



A

B

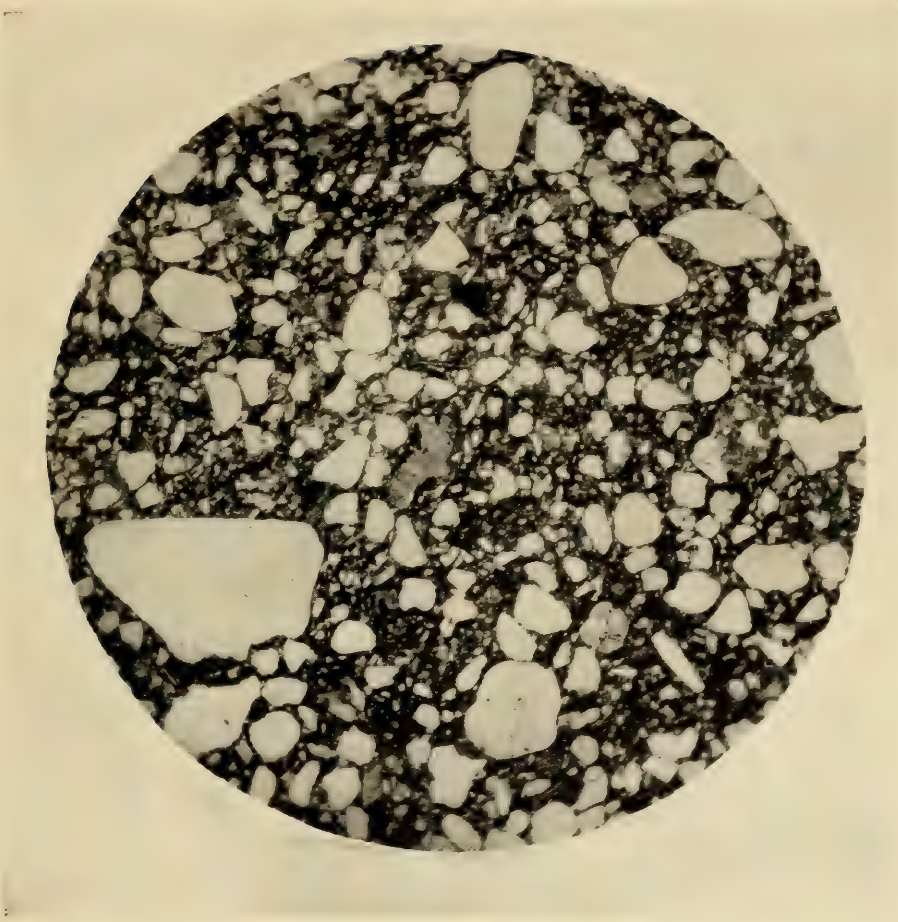
PLATE II

A. PHOTOMICROGRAPH OF "TILLITE" FROM THE HEAD OF SOUTH FORK

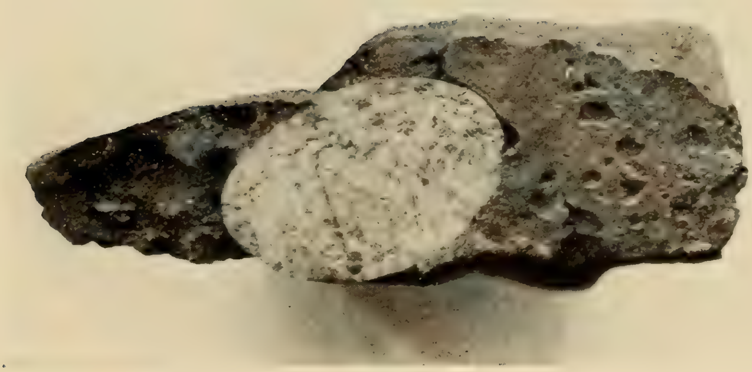
Showing rounded and angular fragments, chiefly quartz, in a dark matrix, principally biotite. Enlarged 25 diameters

B. PHOTOGRAPH OF HAND SPECIMEN OF "TILLITE" FROM SOUTH FORK

Showing rounded quartzite pebble in black groundmass. Natural size



A



B

PLATE III

A. THE DIVIDE AT THE HEAD OF SOUTH FORK AND THE GEOLOGIC EXPOSURES OF THE SOUTH END OF THE READE AND BENSON RIDGE

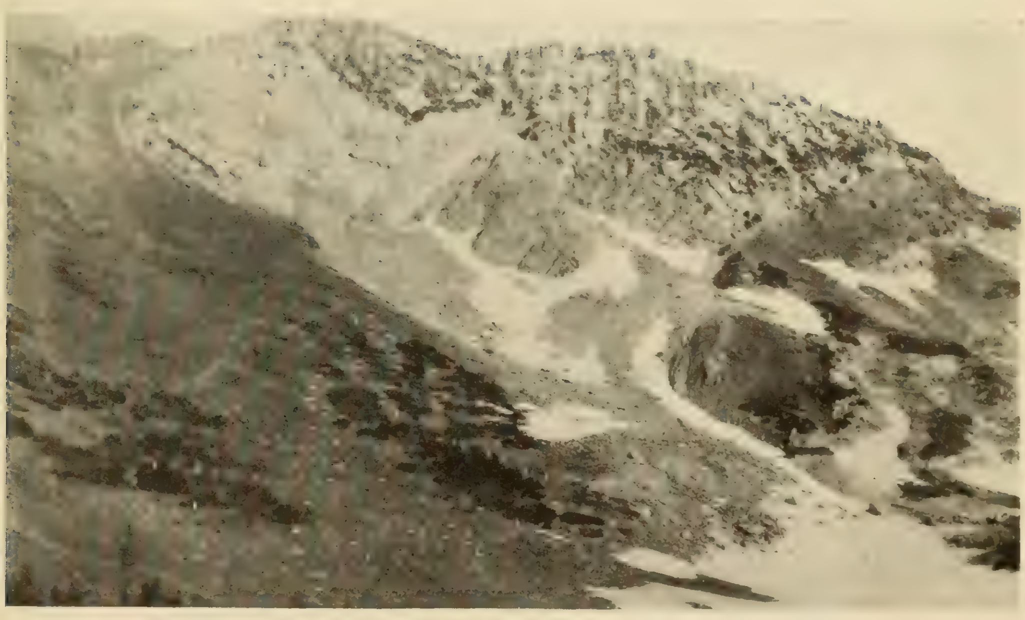
Showing the overthrust members above the Superior fault

B. NEAR VIEW OF THE UPPER CENTRAL PART OF FIG. A

Showing, from left to right, the Cambrian shale, Cambrian quartzite, Algonkian "conglomerate" and quartzite


Ordovicic limestone
Cambric shale
Cambric quartzite
Algonkian Conglomerate
Algonkian quartzite
Superior Fault
Ordovicic and Devonic limestone
Cambric shale (covered)
Cambric quartzite

A



B

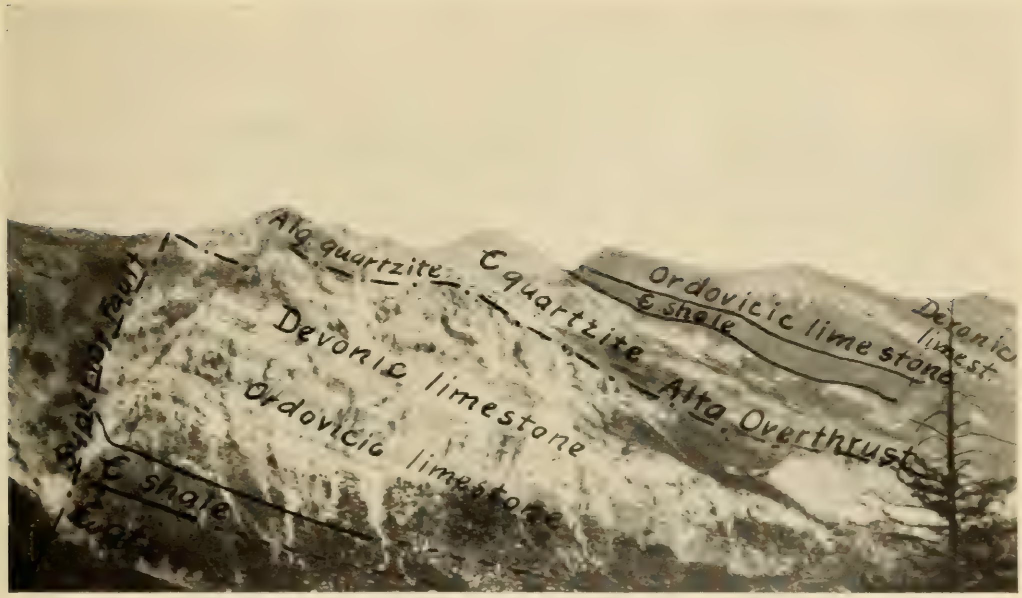
PLATE IV

A. ALTA OVERTHRUST AND GEOLOGIC EXPOSURES ON THE NORTH SLOPE OF LITTLE COTTONWOOD CANYON

Showing the duplication of beds. Looking north

B. NEAR VIEW OF THE EAST-SLOPING ALGONKIAN QUARTZITE SHOWN ON THE RIDGE OF FIG. A

Showing the crumpled layers of hard quartzite


Alta quartzite
Є quartzite
Ordovicic limestone
Є shale
Devonic limest.
Devonic limestone
Ordovicic limestone
Alta Overthrust
Є shale
Superior Fault
Є qtz.

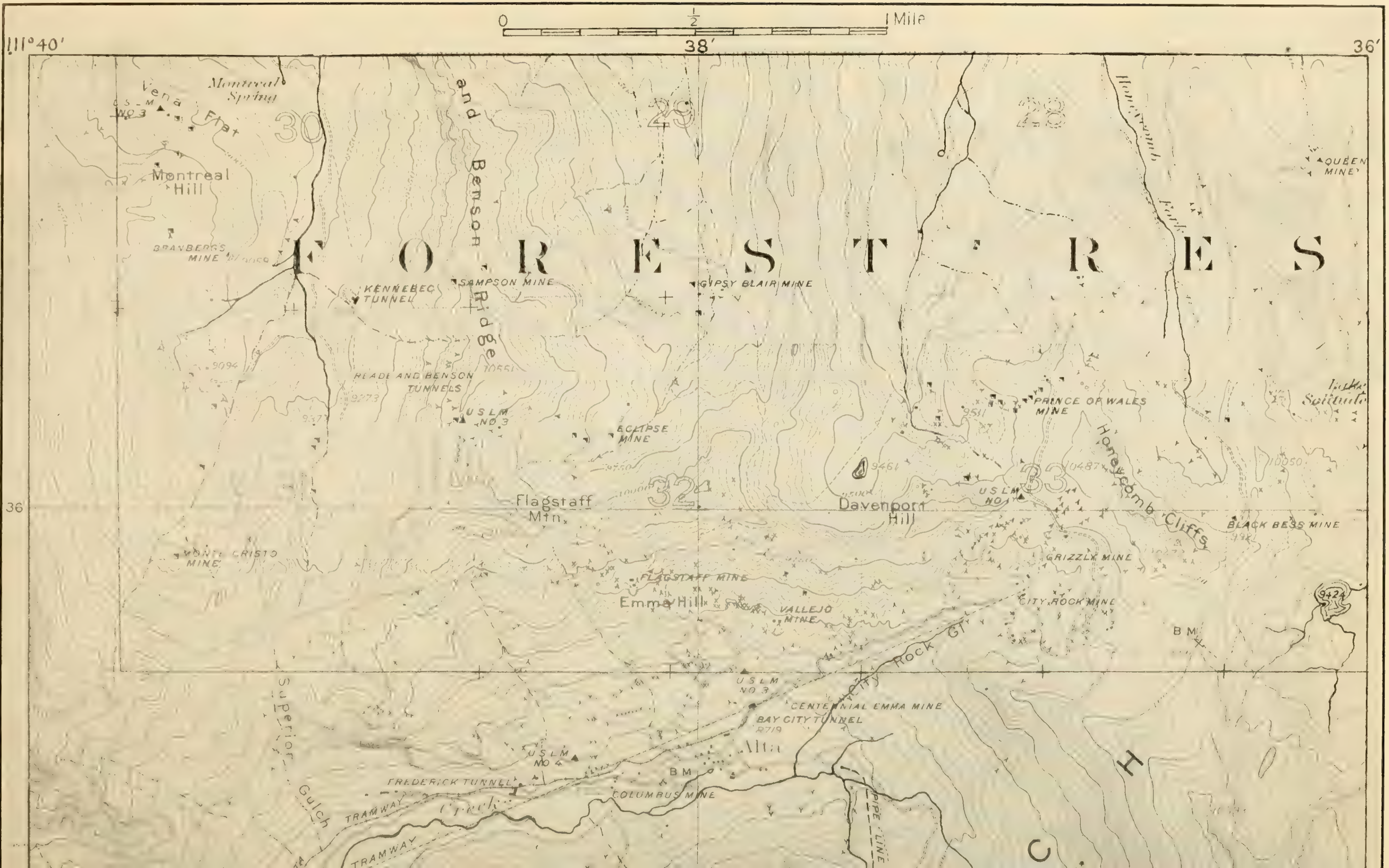
A

B

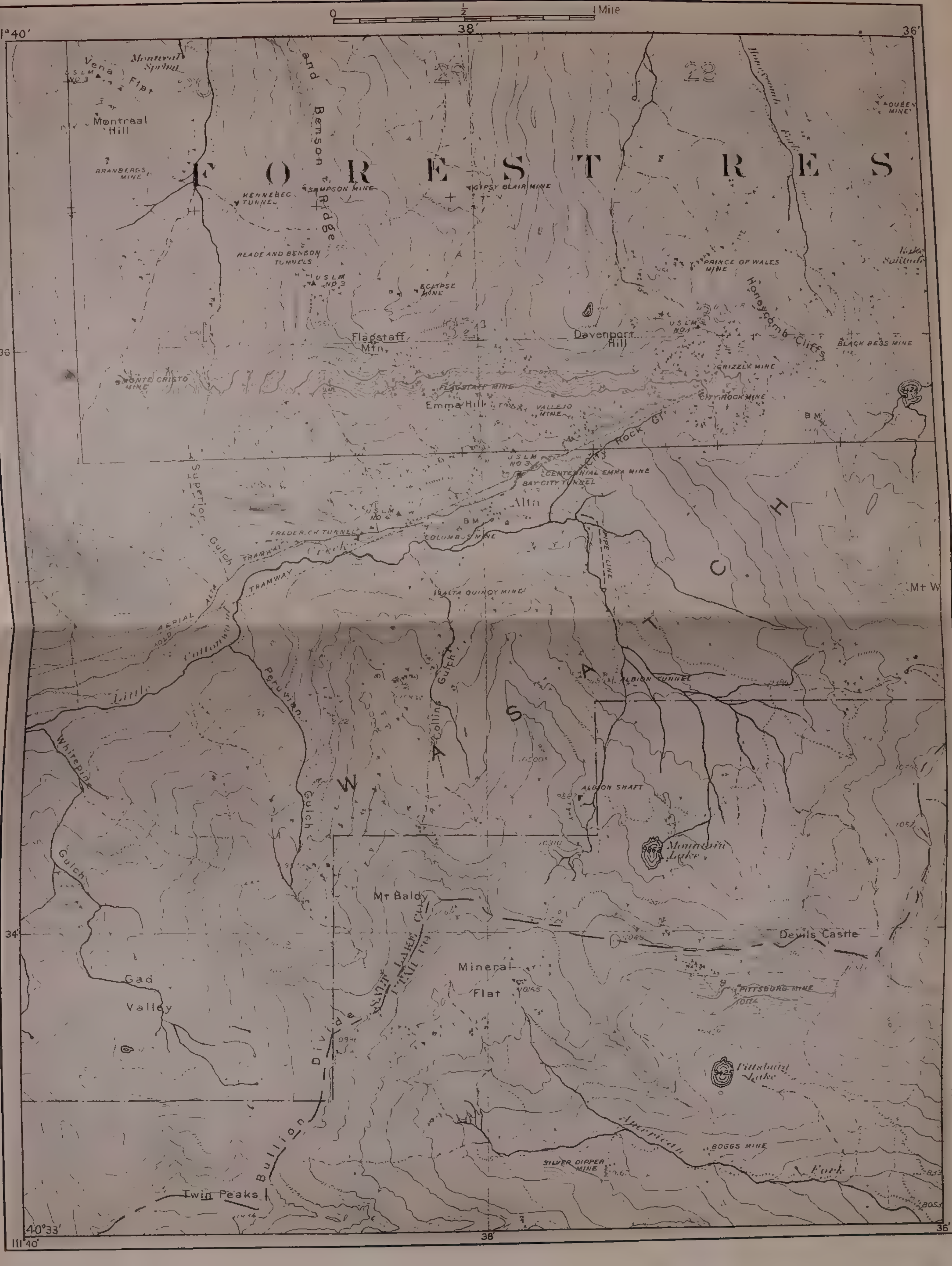
PLATE V

TOPOGRAPHIC MAP OF THE ALTA REGION, WASATCH MOUNTAINS, UTAH

The southwestern part of the Cottonwood Special Sheet, U. S. Geological Survey


0
½
1 Mile
111°40′
38′
36′
36
FOREST RES
Montreal Spring
Vena Flat
U S L M NO 3
Montreal Hill
BRANBERGS MINE
and Benson Ridge
KENNEBEC TUNNEL
SAMPSON MINE
GYPSY BLAIR MINE
HEADE AND BENSON TUNNELS
U S L M NO 3
ECLIPSE MINE
Flagstaff Mtn.
MONTE CRISTO MINE
FLAGSTAFF MINE
Emma Hill
VALLEJO MINE
Davenport Hill
PRINCE OF WALES MINE
Honeycomb Cliffs
U S L M NO 1
BLACK BESS MINE
GRIZZLY MINE
CITY ROCK MINE
Lake Solitude
QUEEN MINE
Honeycomb Fork
City Rock Gl
B M
U S L M NO 3
CENTENNIAL EMMA MINE
BAY CITY TUNNEL
Alta
U S L M NO 4
FREDERICK TUNNEL
COLUMBUS MINE
Superior Gulch
TRAMWAY
Creek
PIPE LINE
9461
10487
10050
9424
9511
9094
9273
30
29
28
32
33

Little
Peruvian
Gulch
Collins
Whitepine
Gulch
W
A
S
A
ALBION TUNNEL
ALBION SHAFT
Mountain Lake
9862
Mt Baldy
SALT LAKE CO.
UTAH CO.
Mineral
Flat
Devils Castle
PITTSBURG MINE
Pittsburg Lake
9425
Gad
Valley
Divide
Bullion
Twin Peaks
American
Fork
BOGGS MINE
SILVER DIPPER MINE
40°33′
111°40′
34′
38′
36′

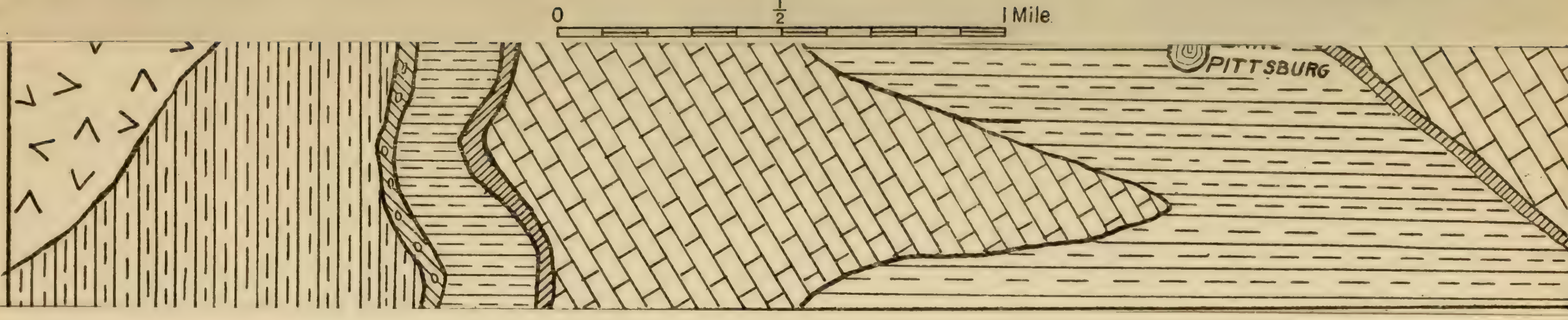


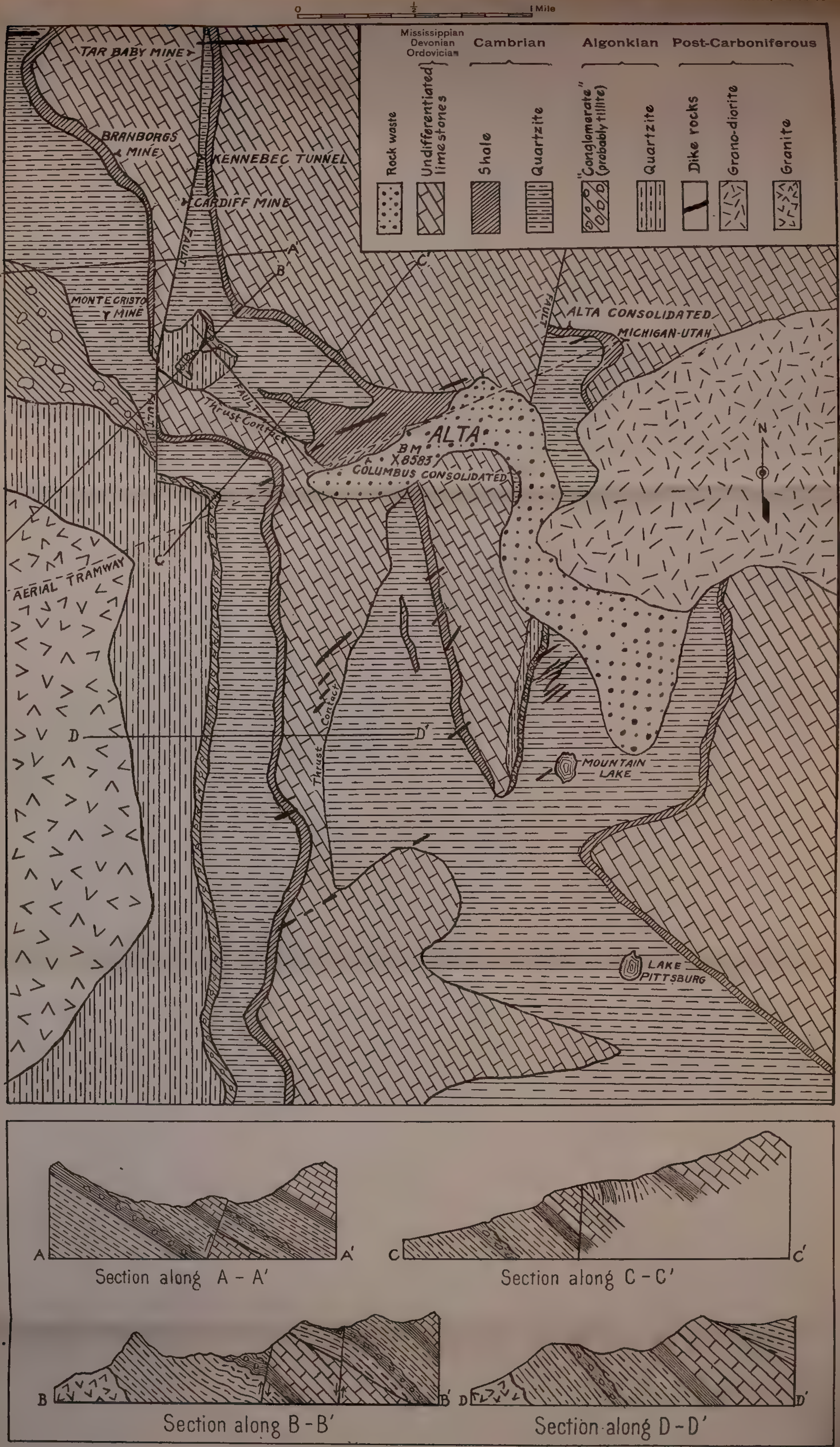
0 ½ 1 Mile
111°40′
38′
36′
36
34′
40°33′
FOREST RES
WASATCH
Montreal Spring
Vena Flat
Montreal Hill
Benson Ridge
Branbergs Mine
Sampson Mine
Kennebec Tunnel
Gypsy Blair Mine
Reade and Benson Tunnels
Eclipse Mine
Prince of Wales Mine
Honeycomb Cliffs
Flagstaff Mtn.
Davenport Hill
Black Bess Mine
Grizzly Mine
Monte Cristo Mine
Flagstaff Mine
Emma Hill
Vallejo Mine
City Rock Mine
Centennial Emma Mine
Bay City Tunnel
Alta
Frederick Tunnel
Columbus Mine
Superior Gulch
Tramway
Aerial Alta Tramway
Pipe Line
Alta Quincy Mine
Little Cottonwood Creek
Peruvian Gulch
Collins Gulch
Albion Tunnel
Albion Shaft
Whitepine Gulch
Mountain Lake
Mt Baldy
Devils Castle
Mineral Flat
Pittsburg Mine
Gad Valley
Pittsburg Lake
Bullion Divide
Salt Lake Utah Co.
Twin Peaks
Silver Dipper Mine
Boggs Mine
American Fork
Mt W

PLATE VI

GEOLOGIC MAP OF THE ALTA REGION, WASATCH MOUNTAINS, UTAH

With structure sections, showing the relation of the Superior fault to the Alta overthrust


0
1/2
1 Mile
PITTSBURG


0
½
1 Mile
Mississippian
Devonian
Ordovician
Cambrian
Algonkian
Post-Carboniferous
Rock waste
Undifferentiated limestones
Shale
Quartzite
"Conglomerate" (probably tillite)
Quartzite
Dike rocks
Grano-diorite
Granite
TAR BABY MINE
BRANBORGS MINE
KENNEBEC TUNNEL
CARDIFF MINE
FAULT
A
A'
B'
C'
MONTE CRISTO MINE
FAULT
ALTA CONSOLIDATED
MICHIGAN-UTAH
FAULT
Thrust Contact
FAULT
ALTA
BM X 8583
COLUMBUS CONSOLIDATED
N
B
C
AERIAL TRAMWAY
Thrust Contact
D
D'
Thrust
MOUNTAIN LAKE
LAKE PITTSBURG
A
A'
Section along A - A'
C
C'
Section along C - C'
B
B'
Section along B - B'
D
D'
Section along D - D'

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Editor, Edmund Otis Hovey

LOCKATONG FORMATION OF THE TRIASSIC OF NEW JERSEY AND PENNSYLVANIA

BY

A. C. Hawkins.

Smithsonian Institution
JUN 18 1914
National Museum

NEW YORK
PUBLISHED BY THE ACADEMY
27 January, 1914

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[ANNALS N. Y. ACAD. SCI., Vol. XXIII, pp. 145-176, Pl. VII. 27 January, 1914]

LOCKATONG FORMATION OF THE TRIASSIC OF NEW JERSEY AND PENNSYLVANIA[1]

BY A. C. HAWKINS

(*Presented by title before the Academy, 29 September, 1913*)

CONTENTS

INTRODUCTION

The study of a recently exposed zone of mineralization in an argillite quarry at Princeton, New Jersey, led the writer to extend his investigations to certain interesting features of the rock formations and general tectonics of the region, a full knowledge of which was found to be essential to the elucidation of the original problem.

The statements herein made are based largely upon observations made during personal field work by the writer from 1910 to 1912. These data have been supplemented by additional facts supplied in publications of the State and national geological surveys, and by work in the petrographical and chemical laboratories of Princeton University.

A bibliography of the publications that furnish the most important references is to be found at the close of this paper.

Grateful acknowledgment is hereby made to those who have in various ways aided in the accomplishment of this work, including members of

[1] Manuscript received by the Editor, 23 September, 1913.

Smithsonian Institution

the faculty of the Department of Geology at Princeton University, Dr. Edgar T. Wherry of Lehigh University and Dr. L. Hussakof of the American Museum of Natural History, New York City.

History

The Lockatong formation is the middle member of the sedimentary series of the Triassic system, as exposed in the adjacent parts of New Jersey and Pennsylvania. Elsewhere throughout the Triassic of eastern North America it is unknown.

The earliest reports dealing with the rocks of this formation mention them only in connection with the quarrying industry of the region. Thus, in the Annual Report of the State Geologist of New Jersey for 1880 (p. 24), a short statement is made concerning Stephen Margerum's quarry in Princeton, which was first opened in 1845. In the issue of this publication for the following year (p. 55), a similar allusion appears. F. L. Nason's discoveries of fossils from the Triassic, reported in 1888 (*idem*, p. 28), include those found in the Lockatong beds. B. S. Lyman[2] wrote a report on the New Red of Bucks and Montgomery Counties, in which the rocks of this middle member are described and named Gwynedd shales. Because however this term was made, on the map at least, to cover rocks clearly referable to other formations, it seemed best to the New Jersey geologists to rename the formation, and in the detailed report Dr. H. B. Kümmel[3] proposed the term Lockatong, which is now generally used. This was further supplemented by an even more detailed paper, published by him in his report for the following year.[4] In 1908, Professor J. Volney Lewis made a careful investigation of the argillites of this series, the results of which were published in the State Geologist's Report for that year (p. 94). Since that time, descriptions of the Lockatong have appeared in the Philadelphia Folio (No. 162), and in the Trenton Folio (No. 167), of the United States Geological Survey, in both of which excellent geological maps of the respective areas are given.

Distribution and Topography

The rocks of this series lie in a slightly curved belt extending from a point some ten miles west of Phœnixville, Pa., to the border of the Cretaceous formation about ten miles northeast of Princeton, N. J. (See

[2] Summary Final Report of the Second Pennsylvania Geological Survey, vol. 3, part 2, p. 2610. 1895.

[3] Rept. State Geologist of N. J., 1896, p. 40.

[4] *Ibid.*, 1897, p. 36.

Plate VII.) The general trend of the belt is thus northeast and southwest, in harmony with that of the local Triassic in particular, and that of the pre-Triassic rocks and of the Appalachian highlands in general.

The course of the Lockatong belt is usually marked by a ridge whose long axis corresponds with the strike of the formation. This ridge commonly has a relief of fifty to a hundred feet or more above the surrounding Triassic area, which is underlain by the somewhat less resistant rocks of the Stockton and Brunswick series. At Phœnixville, it is traversed by two railroad lines, which cross it by means of open cuts and tunnels. Three railroads cross it between this point and the Delaware River, and each of these has required much excavation. At Byram, Hunterdon Co., N. J., there is a long, persistent series of bluffs flanking the river for a distance of four miles, the cliffs at certain places being exceedingly steep and rugged. Between the Delaware and Princeton the topographic effects are not so pronounced. At Princeton the hard rocks, though not very thick, form a ridge, upon which the town has been built.

Upon the Lockatong ridge there is a heavy yellow clay soil, which is typical of the formation. In it are seen many irregular, splintery fragments of resistant dark-colored shale and argillite. These argillite fragments, after a considerable period of exposure to the air, often develop a brown or yellow greasy surface, due to the production of kaolin, which gives rise to the typical sour soils of this belt. These soils, however, are fertile. The high land overlying the Lockatong beds supports an abundance of timber, which, throughout much of the area, has been cleared away to make room for prosperous farms. The drainage is active, and most of the larger streams cut directly across the hard rock ridge.

Stratigraphy

The portion of the Triassic system exposed in this part of the country, usually referred to as the Newark, is composed of three distinct parts or units, which, named in order from the bottom to the top of the series, are the Stockton, the Lockatong and the Brunswick formations. The Stockton formation is composed of coarse conglomeratic sandstones of light colors, usually interstratified with red shaly beds. The Lockatong series of dark-colored, fine grained mud-rocks is the one herein described. The Brunswick formation consists of a very thick succession of red shale beds with some portions that are heavy bedded sandstones, and sometimes well developed conglomerates. The total thickness of the Triassic rocks in New Jersey is estimated to be 18,000 feet. The larger portion of this thickness is made up of red or reddish brown shaly and sandy rocks. The dip, which is fairly constant, averages about 15 degrees northwest, which is normal for the whole system in this vicinity.[5]

The Lockatong formation is thickest in the middle portion of the belt, as appears very plainly when the whole belt is mapped together (Pl. VII and Fig. 1, p. 149). Exposures along the Delaware River[6] further prove that it steadily thickens for some distance westward. Sections of the formation are shown by the river at an average distance of eight miles apart, east and west, on account of the repetition of the beds due to the great Flemington and Hopewell faults, which together have a throw of approximately 17,000 feet. West of Phœnixville, the Lockatong rapidly narrows and finally terminates in a thin edge, its horizon being taken by a heavy conglomerate, apparently of Brunswick age. Northeast of Princeton it narrows considerably; northward of this point, it is hidden beneath a covering of later sediments of Cretaceous and Pleistocene age. Its total failure to re-appear twenty miles farther north, where only the softest of red shales are exposed, has led to the belief that its northward termination is perhaps much like the southern one west of Phœnixville. From these observations, it appears that the Lockatong is a deposit of a decidedly lens-like character. A comparison of the area of the Stockton formation with that of the Lockatong, throughout the extent of the latter, shows that the Stockton varies with the Lockatong, widening and narrowing with it.

The Lockatong consists of a thick series of exceedingly fine grained and close textured rocks. The sediments were so thoroughly sorted that scarcely a single coarse textured layer is to be observed among them in the field. The rocks as they now exist appear as massive, fine grained argillites and shales, the former, on account of jointing, often forming "flagstones" or more massive blocks. The "slates" are often friable, having a cleavage which is too uneven to afford good roofing slate. The color of the shales and of the argillites may be gray, reddish brown, black, or olive green. Red and gray colors often alternate on a large scale. Impure limestone layers one or two inches thick occasionally appear.

The bedding of the Lockatong argillites and shales is very uniform, although a slight irregularity is sometimes present in the bedding of shaly layers. No cross-bedding appears. Ripple marks and mud-cracks occur, the latter sometimes abundantly, in the upper and lower portions of the series.

---

[5] A detailed description of this series is given in the Trenton Folio, No. 167, United States Geological Survey, p. 7.

[6] *Ibid.*, Geological map.

FIG. 1.—*Geological sections across the Lockatong formation from northeast to southwest*

Where continuous exposures are available near Princeton, the succession of beds usually can be observed to be about as follows: At the lowest portion of the section examined (as in McCarthy's quarry, Princeton) there is a thick series of strata of dense, reddish brown, flaggy argillite. At its upper limit the brown bed suddenly loses its characteristic color, and passes, without change in other respects, into a dark gray rock, the most typical argillite of the series. A short distance higher up in the dense gray rock, radiating crystal growths occupy a horizon about a foot thick, with irregularly scattered white crystal specks in the layer immediately above, as hereafter described. Above this horizon there is apt to be an inch or so of very black, carbonaceous shale, followed by one or two inches of a light gray, thoroughly crystalline magnesian limestone. This is again succeeded by an inch of black shale, above which there are gray argillite beds. Still higher more red rocks may appear, and the whole series, as above described, may be repeated.

COLUMNAR SECTIONS

Columnar sections of the Lockatong series are shown in Fig. 1. The sections are numbered from 1 to 7, beginning at the west. They are arranged in order of occurrence, being spaced at approximately correct relative distances horizontally. The vertical scale is made, for convenience, ten times the horizontal. The datum plane selected for correlation of the various sections is the top of the massive argillites, whose deposition marked the time of steadiest sedimentation and most sluggish drainage, which in turn signifies a nearly level surface throughout the area. It is to be noted that this arrangement brings the prominent *Estheria* beds, near the base of the three western sections, to about the same level. The transition beds are represented by black bands where they occur, in the upper and lower part of each section, and the outline of the basin has been completed to show how a repeated interdigitation of the Stockton below and the Brunswick above with the Lockatong might account for the areas of transition.

0. This part of the basin is underlain by dark-colored shales; no argillites appear. At the western end there is a heavy conglomerate, probably of Brunswick age.

1. *Reading Railroad tunnel section, Phœnixville.*

	Feet
Shale, dark red to black (top bed)	380
Shale, brown	380
Argillite, brown	250
Shale, sandy, red and brown; Black shales with estheriæ; Shale, red and brown, transition beds (bottom bed)	490
Total (no important faulting)	1500

2. *Schuylkill River section, Phœnixville.*

Shale and argillite, brown (top bed)	750
Shale, black, with fish scales	50
Argillite, brown	500
Shale, dark colored, with estheriæ	20
Shale, dark red (bottom bed)	380
Total (no faulting)	1700

3. *Perkiomen Railroad section.*

Shale, dark red (top bed)	750
Argillite, brown	500
Beds with estheriæ	10
Argillite, brown	330
Shale, hard and red	330
Shale, gray, with estheriæ	10
Shale, dark red (bottom bed)	200
Probably no important faulting.	
Total	2140

4. *Gwynedd Valley section, Philadelphia and Reading Railroad.*

Shale, dark red (top bed)	720
Argillite, brown	1000
Shale, dark red (bottom bed)	1000
10 per cent reduction made for faults.	
Total	2430

5. *Wycombe section, Philadelphia and Reading Railroad.*

Shale, dark red (top bed)	670
Limy layer with estheriæ, scales and ostracods	1
Argillite, gray and brown	1000
Argillite, with magnesian limestone bands	50
Shale, brown	600
Shale, red	450

	Feet
Sandy beds, green and yellow	60
Argillite and shale, hard and red (bottom bed)	190
Fault of 1000 feet at the top.	
10 per cent reduction made for other (undetected) faults.	
Total	2700

6. *Scudders Falls section, Delaware River.*

Shale, dark colors, alternating at top with red shale (top bed)	
Argillite, black and shaly	
Argillite, black	792
Shaly beds	
Argillite, gray and red	
Shale, black, green, gray, etc. (bottom bed)	1183
No faulting observed.	
Total	1975

7. *Princeton section.*

Shales, red, and argillite, red-brown (top bed)	
Shales, gray	792
Shales, black	
Argillites, gray and reddish brown	264
Shales, gray, black and green	
Argillite (a lens), 20 feet approximately	396
Shales, red and purple (bottom bed)	
Probably little faulting.	
Total	1452

8. This part of the area shows occasional outcrops of gray and red argillites for a distance of ten miles northeast of Princeton. The northward extension of this series is hidden beneath the Cretaceous cover.

The accompanying map of the Lockatong formation (Plate VII) shows its actual extent, and the locations of the sections above described.

Paleontology

Fossil remains are far from rare in the area of the Triassic rocks. At various horizons, from the bottom to the top of the series, records of animal and plant life have been found. In general, these remains occur scattered through the occasional strata of the rocks that possess dark colors, and also often in the light-colored arkosic strata (plants) and in the shales associated with the latter. Mud-cracks, ripple marks, and the footprints of animals have been repeatedly found, the latter most frequently in red shales or sandstones.

The Lockatong is composed essentially of rocks embracing a variety of darker or lighter shades of gray, and, following the general rule, it possesses a considerable fossil content, particularly in those layers which are darkest. The fossils become increasingly numerous and well preserved toward the southwest, the best locality for them being the vicinity of Phœnixville, Pa., particularly the Reading Railroad tunnel at that place, now largely inaccessible. A detailed list of the fossils from this locality, as originally published by Wheatley, is given below.

The fossils are more frequent in the shaly layers than in the massive ones. The collector in the field will usually find traces of fish scales and crustaceans in the blackest shale layers. A few well preserved specimens have been taken from the densest beds of gray argillite, as shown by the cycad fronds obtained from Carversville, Montgomery Co., Pa.,[7] and the splendid frond of a cycad, *Otozamites latior* (Saporta), found in one of the Princeton quarries about 1884, and now on exhibition in the geological museum at Princeton University.

The most important fossils of the Lockatong are the following:

Scales of ganoid fishes, usually separated, but at times in groups in black shale layers. Rhomboidal, enamelled scales, either smooth and without ornamentation (*Semionotus* (sp?)) or ornamented with a pattern of deep furrows and ridges (*Ptycholepis* (sp?)). One maxillary of *Semionotus* was found, together with scales and head parts of this fish, in a limy layer near Wycombe, Bucks Co., Pa.

Estheria. Shells of a phyllopod crustacean. Longest diameter about half a centimeter, usually appearing as flattened disks on the surfaces of black shale. The shells are ornamented with numerous concentric rings, between which in some cases can be seen the "reticulate interspaces" described by T. Rupert Jones.[8] These are abundant in some layers in the southwestern part of the area, as at Phœnixville, and are usually associated with ostracods (*Candona rogersi;* see description in Jones's monograph). Most of the crustaceans found are *Estheria ovata.* Other species of *Estheria* have been reported by C. M. Wheatley, T. R. Jones and T. A. Conrad. Among the specimens collected by the writer, the species *E. ovata* only has been identified. Some tiny shells found at one locality are doubtless the same form in an early stage of development. With the estheriæ and ostracods the scales of *Semionotus* often appear, as at Wycombe.

Certain layers of shale are found to carry numerous microscopic black spines, which do not correspond with those of the ganoid fishes or with those of echinoderms. They may be the setæ or parapodia of the worms whose borings are often seen in the sandy layers. They are, however, too small for positive identification.

Cycad fronds occur rarely, as described above.

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[7] Brown, A. P., "New Cyads and Conifers from the Trias of Pennsylvania," Proc. Acad. Nat. Sci. Phila. for 1911, pp. 17-21.

[8] A Monograph of the Fossil Estheriæ, Paleont. Soc. Lon., 1862.

Of the fossiliferous portions of the Lockatong, the Reading Railroad tunnel at Phœnixville is probably the most prolific.[9] This locality has afforded estheriæ, ostracods, plant remains, coprolites and various mammalian remains, including many bones and teeth. Wheatley reported certain strata full of Saurian bones, and some layers filled with teeth. Certain reddish brown layers were also found to contain abundant carbon derived from organic remains. The species of fossils from this tunnel at Phœnixville are to be fully described in the Honeybrook-Phœnixville Folio of the United States Geological Survey, soon to be published. One of the horizons where specimens of *Estheria ovata* abound is now exposed near the southern portal of the tunnel, where in the black shales they may be found in large numbers and in a good state of preservation.[10]

The following species from this locality were listed by Wheatley in 1861:

PLANTS

Equisetum columnare Brong.
Pterozamites longifolius Emmons.
Gymnocaulus alternatus Emmons.
Fir-cones.
Calamites punctatus ? Emmons.
Plants, seed vessels, etc., genera undetermined.

CRUSTACEANS

Estheria ovata (*Posidonia ovata* Lea.)
Estheria parva (*Posidonia parva* Lea.)
Cypris.
Limulus ?

FISHES

Turseodus acutus Leidy.
Radiolepis speciosus Emmons.
Catopteris gracilis Redfield.

REPTILIANS

Clepsisaurus Pennsylvanicus Lea.
Eurydorus serridens Leidy.
Composaurus — ? Leidy.
Centemodon sulcatus Lea.
Bones and teeth probably batrachian.
Coprolites.
Foot-tracks.

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[9] WHEATLEY, C. M., Amer. Jour. Sci. and Arts, Vol. XXXII, p. 45, 1861.
[10] *Ibid.*, pp. 45-46.

The canal quarry, situated about a mile north of Phœnixville, on the Schuylkill River, yields ganoid scales and plant stems. Some three or four miles farther east, there is a good exposure along the Perkiomen Railroad; north of Oaks station, near the road bridge which crosses the railroad cut, the black shales are filled with estheriæ, with a few fish remains. The next exposure farther northeast is the cut of the Philadelphia and Reading Railroad between Gwynedd Valley and North Wales. From this locality some few fish scales and possibly estheriæ have been reported. Near Wycombe station, on the North Pennsylvania branch of the same railroad, there is a limy layer carrying estheriæ and fish scales, with ostracods. This layer weathers yellow, and is best shown in a small quarry along the railroad, some 1000 feet south of the station.

Many years ago, F. L. Nason[11] found estheriæ at Scudders Falls, on the Delaware River, and fish scales have been reported from this vicinity (Washington's Crossing). Scudder's quarry, one and one-half miles north of Lawrenceville, contains some good scales of both *Semionotus* and *Ptycholepis,* as well as a wealth of tiny black spines or setæ. All these are in the black shales in the center of the quarry, and all occur practically together.[12] Other exposures examined by the writer yielded little except a few obscure plant remains and tiny spines.

Fishes of the *Semionotus* type have been found at many horizons in the Triassic rocks of the New Jersey-Pennsylvania area, as well as in the Massachusetts-Connecticut area. Good specimens have been found in the lower part of the Stockton series below the Palisade trap sill at Weehawken; there are specimens of a similar fish from excavations near Plainfield, N. J. (Warrenville copper mine), in the center of the Brunswick; and the large numbers of splendidly preserved examples from Boonton, Morris Co., N. J., near the top of the Brunswick, are well known. Sunderland, Mass., and neighboring places are also notable as localities for fossil fishes. Of these fish-bearing horizons the Lockatong is but one, and not the principal one. The presence of fish remains throughout the Newark series speaks clearly of roughly similar conditions reappearing at intervals during the time of deposition; and the presence of these remains throughout the Lockatong emphasizes its harmony and unity with the rest of the larger series. A full description of the fossil fishes of this type is given in the Annual Report of the State Geologist of New Jersey, 1904, and more recently by Chas. R. Eastman.[13]

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[11] Ann. Rept. State Geologist of N. J., 1888, p. 29.

[12] Jones, *op. cit.*, p. 88, makes an evident reference to this locality.

[13] "Triassic Fossil Fishes of Connecticut," Conn. Geol. Surv., Bull. 18. 1911.

Petrography and Chemistry

Under the microscope, little can be determined regarding these rocks, except by the use of high-power objectives. The most typical argillite of the densest type appears to be composed mainly of tiny quartz grains of an extremely angular shape, together with a few bleached biotites, and, at times, a little feldspar. In some cases, the feldspars become much more numerous; some of them show well developed plagioclase twinning in wide bands, although the majority are orthoclase. The feldspars are angular cleavage fragments, and appear for the most part perfectly fresh. They are evidently primary constituents, as also the biotite appears to be. The biotite is in small lath-shaped fragments, pale brown in color, showing traces of parallel cleavage and high order interference colors, high relief and parallel extinction. The whole aggregate resembles closely an assemblage of the constituents of some of the gneisses from whose disintegration products the Triassic rocks were undoubtedly derived.

At Byram, Hunterdon Co., N. J., there is a large active quarry in the dense massive layers of the Lockatong. At this locality, as Professor J. V. Lewis[14] has pointed out, the rock is much indurated on account of the proximity of a diabase sill of considerable size and extent. Microscopic investigation of the quarry rock shows that its ground-mass is thoroughly re-crystallized, giving to it an almost flinty hardness, so that it rings when struck with the hammer. The sediments close to the dike are re-crystallized also, and in them there are biotites and hornblendes which seem to have been produced *in situ,* with some areas which appear to be scapolite, as originally described in the publication above noted. The rock at this place is a true hornfels. The effects of the diabase, however, die out within a few hundred feet of it, and such biotites and feldspars as are found in the rocks far removed from igneous action appear to be purely clastic.

The Lockatong series is for the most part free from visible igneous rocks, though it is to be noted that a number of narrow dikes appear. The Lockatong strata in general do not strongly resemble those which have been "baked" by the intrusives, although the derivation of the silica cement, described below, from hot solutions emanating from the intrusives does not seem impossible. The color of the various strata, however, is easily accounted for, with the help of the chemical data at hand, without appealing to igneous action. The reddish and gray phases of the massive argillites are very much alike in every way except color. A massive gray layer is often seen to change upward or downward to a red-

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[14] Ann. Rept. State Geol. N. J., 1908, p. 95.

dish brown color, the transition taking place within a thickness of two inches or less, the texture and general appearance of the rock suffering no alteration otherwise. The percentages of silica and total iron in two specimens of the building stone, red and gray, from horizons twenty feet apart in the Princeton quarries, are almost identical:

Massive red argillite, SiO_2, 46.40 per cent. Total iron, 6.05 per cent.
Massive gray argillite, SiO_2, 46.42 per cent. Total iron, 5.61 per cent.

A content of seven or eight per cent of total iron seems to be normal for these rocks, and some such amount usually appears in the analyses. Thus it is with the following series of analyses:

Determinations of Iron in Lockatong Argillites

Sample	FeO Per cent	Fe_2O_3 Per cent	Total Fe Per cent
1	3.57	7.80	8.28
2	3.65	7.88	8.40
3	1.16	9.38	7.50
4	4.40	3.81	6.10
5	7.15	4.52	8.77
6	9.30	0.91	7.91
7	5.12	4.97	7.50
8	5.65	5.07	7.98

Red Argillite Samples:
1. McCarthy's Quarry, Princeton, bottom of quarry wall.
2. McCarthy's Quarry, Princeton, middle of quarry wall.
3. McCarthy's Quarry, Princeton, top of quarry wall.

Gray Argillite Samples:
4. McCarthy's Quarry, Princeton, middle of quarry wall.
5. McCarthy's Quarry, Princeton, top of quarry wall.
6. Shanley's Quarry, Byram. Analysis by R. B. Gage.
7. Scudders Falls, Traction Company's quarry, bottom of quarry wall.

Olive Green Argillite:
8. Scudders Falls, Traction Company's quarry.

On each of the above, duplicate determinations closely agree.

The percentage of Fe_2O_3 is in every case much higher in the red rocks than in the gray ones. This indicates that the color of the red layers is due to the presence of hematite, while that of the gray layers is partly or wholly due to ferrous iron. This is in accordance with the work of Spring, who obtained results of a similar nature from the study of red and gray sediments of Devonian age.

Certain limestone layers that are occasionally developed to a thickness of one or two inches, which appear light gray and coarsely crystalline on the fresh fracture, but which rust on weathering, contain, on the average, nine per cent of MgO. They are therefore not true dolomites, but should be called magnesian limestones.

The color of all the blackest shales of this formation is due to carbon, which burns off from the powdered sample, heated in a crucible nearly to redness, usually leaving the sample gray in color. The origin of the carbon is in the organic remains, of which traces can usually be found somewhere in such beds. Part of the color of the massive gray layers is due to the same cause.

The iron compound in the argillite is not the cementing material, since, if boiled in concentrated hydrochloric acid for some time, the rocks lose the color from their surface, but the interior of the mass does not disintegrate in the smallest degree. Under similar treatment both the red and the gray rocks of the type referred to behave similarly.

The cement of the strongest and most compact of the massive argillites (those described above, for instance) is opaline silica. The slow maceration of a small solid sample of the rock in a concentrated solution of sodium hydroxide on the water bath, for from 36 to 48 hours, reduces a considerable part of it to slimy mud.[15] The opaline cement was observed some years ago in sections of the rocks by Professor J. V. Lewis.[16] The rocks of this series are, however, of a widely varied character, some layers showing a more calcareous cement, and others having very thin limy layers intercalated with siliceous ones.

Some of the feldspar fragments observed in this rock under the microscope have cloudy or kaolinized borders, and doubtless much finer feldspathic material originally present has disappeared in this way. Kaolinization of feldspars always sets free silica (Clarke). This silica is in a condition to be readily taken into solution by waters of any kind. In this dissolved condition the silica may be imagined to have existed in the still moist muds of the Lockatong. From these solutions the silica would then be deposited as the muds dried. Thus its introduction might be supposed to have taken place contemporaneously with the deposition of the sediments. If, on the other hand, the cementation occurred in the sediments sooner or later after their deposition, the silica might have been introduced at a late period, as some observers have believed, in connection with the great outburst of igneous activity which marked the latter part

[15] SPRING, W. Ueber die eisenhaltigen Farbstoffe sedimentärer Erdboden und über den wahrscheinlichen Ursprung der rothen Felsen. Neues Jahrb. für Min., Geol. u. Paleont. Jahrg., 1899, p. 47.

[16] Ann. Rept. State Geol. N. J., 1908, p. 95.

of Triassic time in this immediate neighborhood. The strata lying between the Lockatong exposures and the nearest visible diabase sill show, however, only occasional horizons of unusual hardness; they are not as a whole much indurated. It further appears that the silica cement was not generally distributed in the vicinity of the diabase sill; and buried intrusives beneath the Lockatong are improbable. For these reasons, the writer favors the idea of cementation after deposition, but independently of the igneous intrusions.

This siliceous cement is evidently a widespread and typical feature of the Lockatong rocks, extending through many hundreds of feet of the formation and throughout nearly all of the seventy miles of its exposed length. It is also to be observed that the strongest rocks, massive argillites whose unusual strength is dependent largely upon this cement, are usually near the central part of the formation, both vertically and horizontally, occupying the middle of the lens.

The existence of the clay soil of the Lockatong belt is doubtless one very important reason why most of the early investigators of the argillites described them as clay rocks, largely composed of kaolin or similar substances. Our present studies, however, would rather lead us to believe that the kaolin, although really present in the soil, is derived, in large part at least, from the alteration of feldspars which exist in the rock in a fresh condition.

Origin

The general shape of the Lockatong as a whole, and its sediments of such exceedingly fine grain and of such uniform texture, give evidence of its mode of origin. Its present outcrop (Plate VII), and the comparison of detailed sections (Fig. 1, p. 149), indicate a lens-like shape, with the finest sediments in the center of the lens, as might be true of a series of sediments filling a basin. The densest and most massive rocks of the series, the argillites, are remarkably uniform in character, being of very even grain and without coarse layers through thicknesses which may be great, as at Byram, where a single bed is forty feet thick, without a well marked parting along any of the bedding planes. Through a thickness of 3000 feet of beds in the Lockatong, there is scarcely a rock exposed whose grains are large enough to be visible to the unaided eye. Sedimentation during the time when these materials were deposited must have been very regular, and the conditions very steady and uniform for a long period. The presence of crustaceans and of ganoid fishes points clearly to the existence, at times, of considerable bodies of water or temporary lakes. A region of freshly deposited, unconsolidated muds, on which lakes could exist for any length of time, must have had a level surface throughout its extent, or else drainage would have been developed and the lakes would have been quickly destroyed. The region may have stood but little above sea level, or, what is more likely, a ridge of harder rocks, perhaps some distance away, blocked drainage at the outlet of the basin. The estheriæ and ostracods are known to be fresh water, or possibly brackish water, forms. Hence the waters in which the Triassic fishes thrived during the same period must have been fresh, or possibly brackish, as the fish scales are found with the other forms mentioned, at Wycombe and elsewhere. This would appear to have some bearing on the problem of the state of the waters in which the same species of fishes lived, at Boonton and Sunderland. The aspect of the whole body of the Lockatong sediments is that of a mass of fine-grained muds, carried down from the higher crystalline uplands surrounding a structural trough, which had been but incompletely filled by the quickly accumulated sediments of the Stockton series. The continued filling-in by these fine materials formed a mud-flat upon which pools of water (playa lakes) gathered, and in time dried up again, leaving large numbers of well formed sun-cracks, and occasional ripple-marked layers, together with the remains of living forms, above described.

The thin limestone layers encountered at and near Princeton may have been deposited as a chemical precipitate, or may be the product of calcareous animal remains. No fossils were found in these layers. It has been suggested that this limestone might be similar in origin to the desert limestone crusts of Africa and the Bad Lands, which are produced by the evaporation of ground waters brought to the surface by capillary attraction. The Lockatong limestones, however, occur in the midst of black shales which usually carry organic remains. Other thin limestones, which contain abundant *Estheria* shells and fragments, may have been formed by solution of the *Estheria* shells themselves.

Throughout the study of these rocks, nothing has been found in them that would in any measure offer proof of a volcanic origin. No coarse material resembling bombs are to be seen in the field, and no trace of anything resembling volcanic ash was observed in the thin sections. In Connecticut, abundant volcanic deposits of the above sorts have been noted in the Trias and described by Emerson and by Davis, but there appears to be a scarcity of such phenomena in the New Jersey-Pennsylvania area. There seems to have been no volcanic activity in this latter section until long after the Lockatong sediments were deposited and buried under an accumulation of perhaps several thousand feet of the overlying

Brunswick beds. What appear to have been the first eruptions in this vicinity took the form of surface flows, the principal members of which now form the Watchung ranges in New Jersey. (See Annual Report of the State Geologist of New Jersey, 1897, Plate III, p. 32.) Even were we to suppose the intrusive diabase of the Palisade-Rocky Hill sill to be earlier than the extrusives, yet, since it cuts through the Lockatong series, it is younger than that series, and could not have furnished material for it. Moreover, an intrusive sill could not form ash. There seems no good reason to expect the occurrence of deposits of volcanic ash before the time of the Watchung flows, although, of course, volcanic ash is often carried for considerable distances by the wind. The petrographic evidence, however, is strongly opposed to such a constitution.

It has been suggested that the Lockatong may represent the finest rock flour of re-worked glacial deposits. While there is no direct evidence favoring this latter supposition with regard to Lockatong deposition, still such an origin may be regarded as a possible one. However, no glacial markings have been observed among the coarse pebble beds of the underlying Stockton formation, nor have they ever been reported elsewhere in the local Triassic. For physiographic reasons also, as explained below, this hypothesis seems rather unsuitable to the case in hand. The numerous investigators of the Triassic formation, both here and abroad, have repeatedly emphasized the possible derivation of the Triassic sediments from rocks which were undergoing the normal process of weathering in warm, humid climates.

The most typical portion of the Lockatong is the central mass of argillites. The central portion of the lens is at its maximum more than 2000 feet in thickness, and is prevailingly gray in color, as it is in the large exposures at Byram. Above this central portion, red, sandy beds begin to appear at intervals, intercalated with a series of dense gray beds of typical Lockatong aspect. Farther upward the gray beds become less and less numerous, and in time cease altogether, when the Lockatong passes into the typical red sandy shales of the Brunswick formation above. These "transition beds," as they are called, are usually several hundred feet in thickness. Below the argillites, the same conditions appear. The upper part of the underlying Stockton series is usually red shale. These red shale beds may be developed to great thickness, as at Raven Rock, N. J., some two miles south of Byram, where they form a cliff high above the river. Above the red shale the dense gray rocks appear, at first only occasionally, and in two-foot layers, then gradually crowding out the red beds, until the whole series is dense and gray. The transition beds are marked by large areas of mud-cracks and ripple marks, and are especially well exposed along the valley of Lockatong Creek, Hunterdon Co., N. J., which is the type section.

N. H. Darton and H. B. Kümmel, in their reports accompanying the recent geologic folios (Trenton and Philadelphia Folios), repeatedly emphasize the presence of wide transition zones on the borders of the Lockatong. For instance, on pages 7 and 8 of the Philadelphia Folio, Darton says:

"These three formations (the Stockton, Lockatong, and Brunswick) are not sharply separated by abrupt changes of materials, but usually merge through beds of passage which appear to vary somewhat in thickness and possibly also in stratigraphic position in different areas."

Poor definition of the boundaries of the Lockatong series is typical on account of the pronounced interdigitation with the formations above and below, which has been the cause of some uncertainty in mapping those boundaries. Its boundaries are rarely if ever definite planes, but are zones of transition from one formation to the other, by alternation of beds. It seems plain, therefore, that a portion of the Lockatong beds that lie along its lower margin are really as closely related to the Stockton formation as to the Lockatong, while several hundred feet of beds, more or less, in its upper portion, might just as reasonably be classed with the Brunswick. The presence of abundant ripple marks and mud-cracks in the transition beds, as at Lockatong Creek, emphasize the evidence of rapidly varying conditions. Along the strike the Lockatong seems to pass into the other sediments, its typical argillites being there represented by rocks of a different nature. The conclusion of H. B. Kümmel,[17] with regard to that portion of the Lockatong series which occurs in New Jersey, would therefore appear to be equally true of the area of Lockatong rocks as a whole. In discussing the absence of the argillites in the general area north of Princeton, he says:

"The most probable explanation for the absence of these beds is, therefore, that the conditions favoring their formation did not prevail in the northern part of the basin; that here the red shales and sandstones were deposited contemporaneously with the argillites and flagstones of the southwest, and that, could we trace the latter from the point near Princeton, where they begin to disappear beneath the Pensauken and Cretaceous deposits, we would find all the steps in their transition to the soft red shales. It follows from this that the term Lockatong, when used apart from the particular rocks to which it was first applied, represents certain *conditions of sedimentation*, which resulted in the deposition of hard shales, flags, and argillites, and not a definite time-period."

[17] Ann. Rept. State Geol. N. J., 1897, p. 41.

For the movement of such fine materials, but little power on the part of transporting agents would be required. It may have been, in part, the work of wind, even though no direct æolian deposits have been observed among the sediments, and thus, as far as present evidence goes, water was the final agent of deposition. The Lockatong sediments were originally very fine muds, which would remain suspended in water a long time before settling, doing so only when the waters became very quiet, or where the moisture dried up. Everything points to the hypothesis that drainage was far from active in the region of Lockatong deposition.

The Stockton beds represent large quantities of bowldery gravels, full of fresh feldspars, distributed over a wide area which must have been covered with abundant standing water, in which the deltas spread out from the shores of the basin toward its center. The Lockatong deposition appears to have been accomplished under a continuation of these conditions. The results were much the same, except that the later sediments were of the finest type, being muds instead of pebble beds. The change in the deposition must have been due to a weakening of the streams, probably on account of degradation of the highlands by normal erosion. The torrential periods of the Stockton gradually ceased, although they appear to have persisted for some time in decreasing strength on the borders of the basin. We may imagine that the fine muds of the Lockatong drifted in and filled up the deeper portions of the basin, which were not already occupied by the rather poorly distributed deltas of the Stockton. According to this arrangement, the Lockatong beds would naturally collect in the central part of the basin, and might contain much re-worked material from the Stockton along the shores, as well as detrital materials coming directly from the older rocks. What sort of material occupied the east and west sides of the Lockatong trough cannot now be determined, as the eastern border has been removed by erosion and the western is buried under the Brunswick series. To the north and south the beds are apparently replaced by the Brunswick and perhaps the Stockton. Whether, during a portion of the time of Lockatong deposition, erosion was actually taking place elsewhere upon the Triassic sediments, is not plain. If this were true, an erosion interval should be indicated between the Stockton and the Brunswick beds to the north and south; in New Jersey, this contact is hidden beneath later deposits, and even in Pennsylvania, the same condition seems to obtain, although the actual relations are not well known. After the close of the Lockatong deposition, the coarse sediments gradually reappeared, giving rise to sandy shales and sandstones. This increased coarseness of sediments shows a renewal of erosional activity which strongly suggests the beginning of an erosion cycle. Hence it is suggested that the Lockatong may mark the close of the erosion cycle which was begun when the Stockton beds were deposited, and that the Brunswick may indicate the beginning of a second cycle, probably brought about by a slight upward warping of some of the land surrounding the basin, which cycle continued through Brunswick time.

Crystal Growths

Much of the Lockatong argillite, even in its densest phases, is charged with disseminated specks of crystalline calcite, usually minute in size. This calcite occurs as often in the red rocks as in the gray, and is probably a secondary filling in spaces from which some earlier material has been leached. It often follows the course of a horizontal stratum, and does not favor the joints.

Apart from the foregoing, there are other growths of a somewhat similar nature, but of more limited distribution, which, on detailed examination, are found to exhibit certain systematic peculiarities that suggest a somewhat more complicated mode of origin. These are curious fan-shaped radiations of white material, which appear most plainly in the quarries at the east end of Princeton, being at times quite conspicuous features. The arrangement, where most typically exposed, is as follows: Filling one stratum, perhaps two feet thick, are sharply defined, slightly tapering lines of white material, which originate at a common horizon defined with great clearness. The white stringers diverge downward from this horizon in slightly curving lines, meeting at the top in points which are definitely spaced, according to the amount of development of the whole. Vertical cross sections of these radiations in different directions, as well as vertical sections of the same portions at right angles to each other, afforded by the corners of joint blocks, show that what we really have is a series of conical arrangements, composed of strings of crystals which radiate downward always. Above the layer of conical development there is usually a zone of a foot or less containing white crystal grains in irregular arrangement, as if considerably disturbed.

Thin sections of these crystals under the microscope show that these are indeed crystal cavities, the appearance of regular outlines in the hand specimen being amply borne out by the appearance in the sections. The cavities at times show very definite angles which outline a form that appears to be of a monoclinic or triclinic type.

In these exposures, the crystal groups follow definite horizons in argillites which are gray, while at Scudders Falls (Traction Company's quarry, on the Pennsylvania side of the Delaware River) one massive stratum with a strong reddish brown color shows a typical development of the same arrangement, although it is not so well developed as in the Princeton quarries.

It is evident that the material now filling these cavities is not original. This filling is composed of an outer lining of isotropic analcite, which has coated the walls of each cavity with free crystals whose outlines plainly show, and calcite, which has filled in the balance of the cavity. It appears that the entire rock mass has been soaked through and through with solutions bearing the same minerals, which are found in excellent development in the larger cavities of the joints. These solutions, as elsewhere demonstrated, had their origin with the intrusive rocks not far distant.

The exact nature of the original mineral that grew here in the Lockatong muds could not be determined from the material available. Some of the crystal cavities occupy positions within the fillings of mud-cracked layers, showing that they grew after the filling of the cracks by deposition of another layer of sediment above. The whole system of conical crystal growths is most unusual. Its similarity to the well known cone-in-cone structure seems only apparent. There is no tendency in the argillites of the Lockatong to break along the lines of crystals; breakage takes place across the cones, along the bedding, showing the crystals following a pattern of wavy lines within the cone. A thin section of cone-in-cone limestone from Erie, Pa., showed no traces of crystal growths along the lines of parting, whose production appears to have been due to pressure alone. Possibly the growths in the Lockatong followed cracks which had been produced by pressure; but it is hard to explain by this method the growth of isolated cones at regular intervals, whose production would require isolated points of intense pressure, similarly spaced. It is more likely that the original mineral was something similar to gypsum, which in its crystallization often follows a radiating habit, and which grew in the mud before induration.

Evidently the animals and plants of Lockatong time, carbon from whose remains so often causes dark colors in these rocks, existed in the general region where they are now found, since ganoid scales in certain localities, as at Phœnixville, are still clinging tightly together. Plants require some moisture, and estheriæ still more, while fish remains indicate considerable bodies of water—playa lakes—of some extent. Dark shales of this character, found in the proximity of limestone layers and carrying fish scales and estheriæ, never have been observed to show mud-cracks, a fact which would indicate that the sediments were constantly covered with water and out of contact with the air. The passage into gray argillites above, in which there is only a trace of carbon, and thence into the red argillites, where there are neither carbon nor fossils, would presumably indicate a gradual decrease in the amount of water present. The growth of crystals within the sediments would seemingly require the presence of a certain amount of moisture, although the quantity of water may have been slight.

Jones,[18] in describing the English estheriæ in particular, says:

> "The recent estheriæ are found in fresh water, rarely in brackish water. Guided by this fact, and taking for granted that our fossils were true estheriæ, and that estheriæ always have had fresh-water habitats, we should suppose that the deposits in which these fossils are found, free from any appearance of having been drifted, must have been formed in rivers, lakes, or lagoons. . . . The recent estheriæ appear, as it were, suddenly, in pools and ditches of rain-water, and are quickly developed in tanks or ponds dry even ten or eleven months of the year. . . . At all events, there is no necessity for supposing them to have been marine; but where they occur by themselves, or in company only of fishes and plants (the association of remains of land-plants with the estheriæ is of frequent occurrence), they may be regarded as having lived and died in fresh (or possibly brackish) water."

All this goes to show that the waters where the estheriæ lived during Lockatong time were not the waters of the sea, but were rather those of inland playa lakes, such as have been described. Under these conditions, part of the sediments were deposited where there was much organic matter. The carbon present, under the prevailing conditions of moisture and soft sediments, speedily reduced the iron in those sediments to a low state of oxidation, and the color of the mud became gray. Certain strata of greenish argillites, whose color, as shown by chemical means, seems to be due to iron silicate, occur at Ewing, Scudders Falls and elsewhere. These layers are seamed with ramifying stringers of red mud which extend downward from an overlying red bed for two feet or so into the green sediments. This red material is evidently mud which has descended from above, filling deep mud-cracks in the earlier material. The fact that such exceedingly deep mud-cracks could form and remain open in these green muds shows that they must have remained damp throughout for a long time. This agrees with our hypothesis that organic matter in the moist sediments had time to reduce the iron in them. Mud-cracks are common in the red argillite layers in places, but so far as the writer has observed, they never appear deep. This shows that the red mud had an opportunity to dry quickly, and under such conditions any organic matter present was oxidized and disappeared, so that iron in the ferric state remained, giving a red color to the rock. The small residue of carbon remaining in the gray layers is the macerated remnant left after the reduction of the iron.

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[18] *Op. cit.*, pp. 7-8.

Chas. M. Wheatley, in his studies at the Phœnixville tunnel in 1861, observed this phenomenon, which has been found to be very common throughout the extent of the Lockatong rocks. In the tunnel he found "olive green shale, with red veins," and above it, "red shale." Red stringers in olive green rocks, or angular fragments of the green material in a reddish matrix, are often in evidence. Red fragments in a green matrix, or green filling in red rocks, has not been observed by the writer, although such a phenomenon is recorded by Dr. Kümmel.[19]

Tectonics

There are, in the Lockatong rocks, three principal directions of fracture. The first of these marks the lines of original bedding in the strata, and along this series, except in a few cases, little movement has taken place. The major joint series, which is strongly developed, causes a separation along parallel plane surfaces nearly at right angles to the bedding. There is also a parting at right angles to the other directions named. The blocks resulting from fracture in these three directions are rectangular in shape, serving most admirably the purposes of building construction. Such fracture as is here described is perhaps best shown in the "flagstone" layers of the formation.

The major joint series strikes usually forty degrees, more or less, east of north. These are usually vertical, clean-cut joints. At an angle of about twenty degrees to the major joint series there is a minor series of joints, striking, in the Princeton area, from due north to north forty degrees east. This series has a dip of seventy-five degrees toward the east in the case cited. It can be seen on a large scale in Shanley's quarry at Byram. Two joint series at a relatively small angle to each other may be explained by the theory of "rotational strain," as put forward by C. K. Leith.[20] At times an incipient slaty cleavage occurs, having a diagonal direction, and causing the argillites and shales to develop deeply fluted surfaces of parting along joint planes.

Nothing has been seen either in the rock sections or in chemical work on solid chips, which would indicate any important arrangement of the exceedingly small grains, save in the direction of the bedding. Therefore it appears that the direction of the major joint series must be independent of the smaller structures of the rock itself, *i. e.*, that the cause of its direction must be looked for without.

Along the major joint series there has been some movement. This has

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[19] Ann. Rept. State Geol. N. J., 1896, p. 44.

[20] "Rock Cleavage," U. S. Geological Survey, Bull. 239, p. 112. 1905.

taken place in a horizontal direction, being in the nature of a shove or heave without much deviation from horizontality. Such movement has been quite general throughout much of the formation. It appears to have been the result of a tension which opened each crack with a twisting motion, often bending strips of one wall across the cavity without breaking. This is much like the phenomenon which Dale[21] observed in Vermont, and which he described in the Sixteenth Annual Report of the United States Geological Survey. In some cases, as shown by the Princeton exposures, the movement tore strips completely away from the rock walls, and in others, crushed sections which were weak or exposed, forming triangular areas of intense brecciation at points of intersection with the older joint series which it crosses. The sharp brecciation would indicate that the movement took place suddenly, after the rock had become thoroughly hardened, and within a distance of the ground surface not too great to allow the rocks to be within the zone of fracture. Probably the load above was relatively small. The angular fragments of argillites in the breccias appear to be perfectly fresh and unaltered, even at the very margins, when examined macroscopically or microscopically. The minerals surrounding the fragments, the earliest and most important of which were ilmenite, brookite and analcite, must therefore have been introduced soon after the formation of the breccia.

In some portions of the breccia, the fragments of rock appear to be some distance apart from each other, many at first appearing as if they might be entirely free from any point of contact with other breccia fragments or with the walls of the fissure; that is, they appear to be suspended in the vein filling. A systematic study of favorable portions of the breccia, by observation of successive surfaces of a specimen ground down on a lap, shows that the fragments are very irregular, and that each rests against its neighbor at one or more points. This helps to show that the solutions from which the minerals were deposited came in slowly, while from them the minerals here found gradually crystallized. Francis H. Butler,[22] in October, 1911, published an account of an investigation of brecciated material, wherein somewhat similar methods were described. Attention is especially called to Plate V, accompanying Mr. Butler's paper. The breccias which he has chosen, especially in Figures 12-15, are identical in appearance with some of those from Princeton.

The major joint series, as developed near Princeton, is very persistent in strength and direction, being always approximately north forty de-

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[21] "Structural details of the Green Mountain region," U. S. Geol. Surv. 16th Ann. Rept., p. 15. 1894-1895.

[22] "The brecciation of mineral veins." Min. Mag., Vol. XVI, No. 74, October, 1911.

grees east, even at Byram. North of the Rocky Hill trap sill this joint series appears, in the shales, and in the borders of the intrusive diabase, but apparently not within its central portion, where the joints are curving and irregular. The lines of major jointing show a tendency toward verticality, although they sometimes hade about ten degrees east. It is to be noted that this vertical position has little significance, as the joints have probably been tilted more or less since formation. Moreover, a knowledge of the precise direction of this or any other joint series, as pointed out by Leith, and of the direction in which its walls appear to have moved during tension, does not fully inform us as to the real direction of the force which produced the tension. "It may not be certainly determined what combination of stress and strain conditions have been present throughout the development of a given cleavage, although the relations of cleavage to the final total strain may be known," as he remarks on page 113 of his bulletin. All that we can safely say, then, is that the tension occurred in a northwest and southeast direction in this part of the Lockatong belt. This tension acted in some cases from one side of the joint series, and again from the other.

In explanation of the production of this major joint series in the Lockatong formation, and of the minerals therein contained, the writer advances the following hypothesis:

The occurrence of titanium minerals in the fillings of these joint fissures is one of the most interesting and important features. Titanium, while abundant in disseminated condition in many rocks, is seldom segregated in one place. Brookite and ilmenite are found in our mineralized zones, and while they are present only in small amount, are of very beautiful development. Ilmenite has been found at Princeton, in tension joints and breccias. Ilmenite of exactly the same habit and of closely similar form has been found at Byram, occupying tension joints, demonstrably similar in nature and method of production to those of the above locality, and in this latter case only fifty feet from an intrusive diabase sill, so close to the trap that its derivation from the latter would seem certain, in view of large quantities of ilmenite which are known to form part of the normal constitution of the trap, and of the analcite and other zeolites in which the ilmenite is implanted. Ilmenite has also been discovered close to the diabase at New Hope, Bucks Co., Pa. It is embedded in tourmaline crystals in the baked hornfels above the trap, and some much altered sandstone layers there are at times quite highly charged with it.

The tourmalines in the hornfels were produced by the expulsion of boric acid solutions from the trap while it was crystallizing, as explained by

Dr. E. T. Wherry.[24] With the tourmaline, in some stage of its formation, ilmenite crystals were produced, some of which are inside the tourmaline, but most of them in shallow pits on its outer surface. There is good reason for thinking that the diabase sill at Byram was produced by the same igneous outburst which gave rise to the Palisade sill and its supposed extension, the diabase at New Hope. The Byram and New Hope ilmenites, and also those at Princeton, are probably very nearly or quite contemporaneous. At the time of the expulsion of the titanium from the trap, the tension joints were formed by horizontal heave, as is shown by the Byram deposit in one of them. The trap also was affected by this movement, and joints in the same direction were strongly developed on its margins, but as the central part of the mass was perhaps still fluid, it did not develop the same joint system, but curving joints appeared later, which show only in a general way a tendency to take the same direction. Several fault planes of similar nature in the Pennsylvania Triassic are filled by diabase dikes, which shows that some fluid diabase was probably present at that period. The ilmenite, analcite, etc., in these joints were hence undoubtedly derived from the trap rocks in their cooling stages.

This system of joints is notably parallel to the Flemington-Hopewell fault series. It is not, however, strictly of the same age, since the movement of the above named faults has been strongly vertical, without any known horizontal component. Such a fault as the Flemington-Hopewell one, with a throw of 17,000 feet, indicates a disturbance of large dimensions in the basement rocks below. The resulting strain effects upon the Triassic must have been widespread and thoroughly distributed. This faulting did not, of course, take place all at one time. The great Flemington fault has probably been of very gradual production. Movement along this line is evidently still taking place, as shown by the not infrequent earthquakes experienced in Doylestown. Probably the first indication of this movement was a little sagging under the center of the basin, accompanied by the formation of a slight syncline in the later rocks above. In the formation of this syncline, the lower layers of the Triassic were stretched. The most brittle layers, among which were the Lockatong beds, gave way first, and tension joints were formed. As the disturbance increased, the movement was changed wholly to vertical, taking place along a few major lines of fracture, represented by the Flemington and Hopewell faults. The almost total freedom of the Lockatong formation in Pennsylvania from vertical faults of any considerable magnitude is

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[24] "Contributions to the miner. Newark group of Pennsylvania." Trans. Wag. Free Inst. Sci. of Philadelphia, Vol. VII, Feb., 1910.

attested to by the long exposures which show individual strata extending for many hundreds of feet without interruption.

Such a hypothesis as the above would place the beginnings of the Flemington-Hopewell fault series at a time immediately following the intrusion of the Palisade-Rocky Hill diabase sill. Since this fault series affects practically the highest horizons of the known Triassic in the New Jersey-Pennsylvania section, this would place the intrusion of the Palisade sill at a time about the close of the Triassic period of deposition here represented, or perhaps a bit later.

The joint series which is at right angles to the principal series was of earlier production, and must have been tightly closed and discontinuous, since it contains none of the mineral deposits above described.

With the ilmenite and analcite in the major joints and brecciated zones at Princeton, crystallized barite appears. A quantity of barite is present at Glenmoore, near Hopewell, N. J., and another similar deposit exists at the western end of Buckingham Mountain, in Bucks Co., Pa., where the Flemington and Hopewell faults unite. In both of these localities the barite occupies a breccia, being evidently typical of this series of fault zones. Barite has been found in cavities of the Palisade diabase, at Bergen Hill, N. J., in crystals two or three inches long and an inch thick. Without doubt most of the local barite originated with the trap rocks, as did the barite found with the ilmenite and analcite at Princeton. The analysis, however, of R. B. Gage[25] shows that at least some of the Lockatong sedimentaries carry as much as 0.11 per cent of BaO. The circulation of waters through such a rock might account for small occurrences of barite.

Titanium minerals, such as the ilmenite and brookite which appear in such good development, require heat for their artificial production. Little is known, however, of their exact mode of formation in nature. Analcite is commonly associated with the minerals of the trap rocks, although under very special circumstances it may be produced in other ways; it does not require excessive heat for its production. The finding of analcite as a close associate of minerals derived directly from the trap while cooling, has a possibly important bearing on the origin of analcite in some other localities where it is associated with the trap rocks. The discovery of analcite with "Eisenrosen" of ilmenite and well formed brookite crystals, on joint planes of sedimentary rocks, having at first sight no connection with igneous action, is a matter of much interest.

The Rocky Hill-Palisade diabase sill, although now much reduced by erosion, must once have overlain much of the vicinity of Princeton. The

[25] Ann. Rept. State Geol. N. J., 1908, p. 96.

prevailing dip of fifteen or twenty degrees would carry the trap a minimum distance of 1500 feet above the mineralized zone at Princeton. The most strongly and typically mineralized zone extends at intervals from Princeton to Rushland, Pa., the whole of which area is flanked on the north by an irregular diabase sill whose original extension may have been 2000 feet or so above the present exposed Lockatong. At the north end of the formation, the Rocky Hill diabase extends up through it, and being very irregular, may extend under it, or may be connected with a sill which lies under it. The presence of small but persistent dikes to the south attest to the presence there of at least some igneous activity. Brookite is, moreover, seemingly authentically reported from Phœnixville.

Solutions that originated with the intrusive rocks of the Triassic usually travelled upward rather than downward. This is shown to a great extent in the region just northwest of New Brunswick, N. J., where the shales are filled with frequent small copper deposits that have come up in solution from the diabase below. Such solutions travelled upward because there were more open cracks and fissures above the intrusive than below it. Large fissures such as fault zones, as at Menlo Park, furnished channels along which solutions rose for thousands of feet. Mineralized solutions were, however, abundantly present below the slowly cooling trap, as well as above it.[26] Ilmenite crystals have been noted in feldspar seams just below the Palisade sill. In case a well developed series of open cracks existed at the time of intrusion, or such a series were opened by some widespread force acting before the intrusive had fully cooled, such solutions might find their way a long distance downward. Unless such action can be supposed in the vicinity of Princeton, we must look for the origin of these mineral deposits in another intrusive at a lower horizon, which would occupy a position beneath the Lockatong rocks of Princeton and the region south for some distance. The existence of such an intrusive, while possible, finds no proof in any evidence gathered in the field.

In some of the exposures, notably at Princeton and at Lawrenceville, vertical joints are coated with a thin film of black bituminous matter. This material resembles anthracite coal or one of the dense asphalts. Its luster is bright and its fracture conchoidal. It has been derived from disseminated organic matter of the black shales, and, circulating as liquid or gaseous hydrocarbons, it has been deposited in the vertical joints, which were the only available openings. Whether its concentration is connected with the injection of the diabase is a question; but as just such bituminous matter is seen on vertical joints at many points throughout the Newark series, any such connection is improbable.

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[26] See reports of the State Geologist of New Jersey for 1906 and 1907.

Mineralogy

A crystallographic study and discussion of the minerals found within the boundaries of this formation has already been published by the writer;[27] it serves as a summary of those species which, to the writer's knowledge, have been found in this region, up to the spring of 1912. This description applies particularly to the deposits lying between Princeton and the Delaware River.

Most of the best exposures, where minerals are obtainable, are in quarries now being operated, where the continued accessibility of these deposits is well assured, and new occurrences are almost certain to appear. Most of the productive deposits are in seams carrying analcite, but many of the calcite seams also will be found to be interesting.

Commercial Aspects

Some criteria for testing a rock in order to determine its availability for building material are given by Dr. Chas. P. Berkey in his report on the Catskill Aqueduct (p. 199). Among these are the following:

Specific gravity.
Weight per cubic foot.
Porosity, in per cent.
Per cent water absorbed.

The tests here enumerated were tried upon samples of the Lockatong argillites, with the following results:

The specific gravity of a specimen of the argillite from Princeton was found to be 2.57. Hence the weight per cubic foot of the Princeton material is 160.62 pounds. This agrees closely with the estimate of a contractor using this stone in Princeton, and also with the weights of many standard building stones in use at the present day.

A specimen of the hard reddish brown argillite from Matthews's quarry, Princeton, was ground to a nearly cubic shape, with smooth faces about an inch square. This block was dried for 6 hours in an air bath at a temperature of 130° Centigrade. It was then removed, and immersed in a beaker of distilled water, in which it was boiled for half an hour, until no more air bubbles appeared on its surface. The surface of the block was then dried off quickly, and upon weighing the sample was found to have taken up .0014 per cent of its weight of water. This test shows that the pore space of the argillite is exceedingly small, and that the penetration of water into the rock is slight. The latter fact is well

[27] Amer. Jour. Sci., 4th series, Vol. XXXV, pp. 446-450. 1913.

shown in the quarries, where rock that has been immersed in water for long periods will be found upon breaking to be perfectly dry inside, with the exception of an eighth of an inch next to the surface. The small amount of pore space is caused by the extreme fineness of grain and by the siliceous cement with which the rock is filled. Since water is unable to gain access to the interior, the damage to the rock by frost is scarcely perceptible. The effects of expansion and contraction with changes of temperature are also slight.

The argillites will melt at about 1100° Centigrade. It is not safe, therefore, to employ them for structural material in chimney linings or in other places where they may be exposed to intense heat.

The argillite is evidently a very strong and resistant rock, and it has successfully stood the test of the last one hundred years in such buildings as were constructed of it. On account of its varied colors, the argillite has been used with pleasing results in the construction of some of the newer dormitories at Princeton University. It is being extensively employed in the new Graduate College connected with the university, and in the new High School building at Princeton. Its use in concrete construction has been extensive in the Graduate College; it seems to serve the purpose well, except that the argillite fragments are sometimes too smooth to offer a good surface for firm adhesion of the cement. There seems to be no reason for believing that this rock is not as good as trap rock for many of the purposes for which the latter is usually employed; the trap rock, moreover, often has the disadvantage of much greater coarseness, and a corresponding degree of susceptibility to the destructive action of the weather. The argillite, as a building material, should be more widely known.

Summary

The Lockatong formation is the middle member of the Newark series of Triassic rocks, extending from a point just west of Phœnixville to the vicinity of Princeton.

The rocks constituting the formation are dense, fine-grained, massive mud-rocks known as argillites, with some shales. The formation as a whole has a decidedly lens-like character. The present investigations have led us to believe that these sediments were laid down in an inland basin, and probably in the center of that basin. This hypothesis is supported by the general structure as observed in the field, by the testimony of the fossil estheriæ, fish scales, ostracods and plant remains found within its layers and by chemical studies. The color of the rocks is largely due to iron in various states of oxidation, the presence of which

in these states is more probably the result of normal processes of deposition than of alteration by igneous or other later action. The cement is for the most part silica, the origin of which is by no means easily established, but which does not seem to require abnormal processes or later alteration for its introduction. Some horizons in the Princeton area contain regularly arranged strings of crystal cavities radiating downward in conical groups. These seem to have been crystals which grew in the sediments, while the latter were still soft. Their growth in wet muds perfectly agrees with the other known features of the rock, and they seem to have a definite place in the sedimentary cycle of deposition. Their unique arrangement is as yet unexplained.

The Lockatong formation, while composed in the central part of massive argillites, is much more shaly on the margins, and passes by gradual stages into the other Triassic formations above and below it, through a series of dove-tailing strata. Hence its boundaries are very uncertain, and large portions of its upper and lower parts may as well be said to belong to the series above or below as to the Lockatong. Therefore it is our conclusion, which is similar to that stated by Dr. H. B. Kümmel,[28] that the Lockatong series, as a definite geological time unit, is probably valueless, since part or all of the formations seem to be contemporaneous with portions of the Stockton and Brunswick series elsewhere.

There are three principal joint directions, the most important of which, occupied by the major joint series (tension joints), is remarkably constant in direction throughout the area. It affects all the Lockatong rocks, and is also found on the borders of the intrusive diabase mass of Rocky Hill, an extension of the Palisade sill, but not far within the latter. Titanium minerals—brookite and ilmenite—are found in these joints, apparently far removed from diabase, together with analcite and barite, whose derivation from the intrusive rocks is indicated by the occurrence of the same minerals in similar joints in the immediate vicinity of the trap rocks at Byram, Hunterdon Co., N. J., and elsewhere. The occurrence of such minerals in the joint cavities of sedimentary rocks, two miles from the nearest visible igneous rock, is worthy of special note. The hypothesis is advanced that these major joints were formed very soon after the intrusion of the igneous mass, at the beginning of a tectonic disturbance which widely affected the Triassic beds; and that later movement took place along a very few major fault lines.

The Lockatong argillite is very dense and close grained, as shown by experiment. This, together with its remarkable siliceous cement and the

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[28] KÜMMEL, H. B. Rept. State Geologist of N. J. for 1897, p. 41.

absence from it of minerals which might decompose, renders it a very strong rock. It has been and is being used extensively as building material in Princeton, and it should be better known elsewhere.

Bibliography

Berkey, Chas. P. Geology of the New York City (Catskill) Aqueduct.
N. Y. St. Mus. Bull. 146. Albany, 1909.

Brown, A. P. New Cycads and Conifers from the Trias of Pennsylvania.
Proc. Acad. Nat. Sci. Phila., pp. 17-21. 1911.

Butler, Francis H. The Brecciation of Mineral Veins.
Mineral. Mag., Vol. XVI, No. 74. October, 1911.

Clarke, F. W. The Data of Geochemistry.
U. S. Geol. Surv., Bull. 491. 1911.

Dale, T. Nelson. Structural Details of the Green Mountain Region.
U. S. Geol. Surv., 16th Ann. Rept., p. 549. 1894-'95.

Davis, W. M. The Structure of the Triassic Formation of the Conn. Valley.
U. S. Geol. Surv., 7th Ann. Rept., pp. 455-490. 1888.

———. The Triassic Formation of Connecticut.
U. S. Geol. Surv., 18th Ann. Rept., pp. 1-192, 1896-'97 (1898).

Eastman, Chas. R. Triassic Fishes of Connecticut.
Conn. Geol. Surv., Bull. 18, pp. 1-75. 1911.

Gage, R. B. Determination of Ferrous Iron in Magnetite.
Jour. Am. Chem. Soc., 31, pp. 381-385. 1909.

Hawkins, Alfred C. Some Interesting Mineral Occurrences at Princeton, N. J.
Amer. Jour. Sci., 4th Ser., Vol. XXXV, pp. 446-450. 1913.

Jones, T. R. A Monograph of the Fossil Estheriæ.
Paleont. Soc. Lon., 1862.

Leith, Chas. K. Rock Cleavage.
U. S. Geol. Surv., Bull. 239. 1905.

Lewis, J. Volney. Building Stones of New Jersey.
Ann. Rept. State Geol. New Jersey, 1908, part III.

Lull, R. S. The Life of the Connecticut Trias.
Amer. Jour. Sci., 4th Ser., Vol. XXXIII, pp. 397-422. 1912.

Lyman, B. S. The New Red of Bucks and Montgomery Counties.
Summary Final Report, Second Pennsylvania Geological Survey, Vol. 3, part 2, p. 2610, 1895.

Nason, F. L. Ann. Rept. State Geol. New Jersey, 1888, pp. 28-29

New Jersey. Annual Reports of State Geologist, 1880, 1881, 1888, 1896, 1897, 1906, 1907, 1908.

Russell, I. C. Correlation Papers; The Newark System.
U. S. Geol. Surv., Bull. 85, pp. 126-131. 1892.

Shaler, N. S., and Woodworth, J. B. Geology of the Richmond Basin, Virginia.
U. S. Geol. Surv., 19th Ann. Rept., pp. 385-519. 1897-'98, 1899.

Spring, W. Ueber die eisenhaltigen Farbstoffe sedimentärer Erdboden und über den wahrscheinlichen Ursprung der rothen Felsen.
Neues Jahrb. für Min., Geol. und Pal., Jahrg., 1899; 1 Bd., erstes Heft, p. 47.

UNITED STATES GEOLOGICAL SURVEY.
Trenton Folio, No. 167 (N. J.-Pa.), p. 7.
Philadelphia Folio, No. 162 (Pa.-N. J.-Del.), p. 8.

VAN HISE, CHAS. R. A Treatise on Metamorphism.
U. S. Geol. Surv., Monog. XLVII, 1904.

WHEATLEY, CHAS. M. Remarks on the Mesozoic Red Sandstones of the Atlantic Slope, and Notice of the Discovery of a Bone Bed Therein, at Phœnixville, Pa.
Amer. Jour. Sci. and Arts, Vol. XXXII, pp. 41-48. 1861.

WHERRY, EDGAR T. Contributions to the Mineralogy of the Newark Group of Pennsylvania.
Trans. Wagner Free Inst. Sci., Vol. VII. February, 1910.

———. North Border Relations of the Triassic in Pennsylvania.
Proc. Acad. Nat. Sci., Phila., 1913, pp. 114-125.

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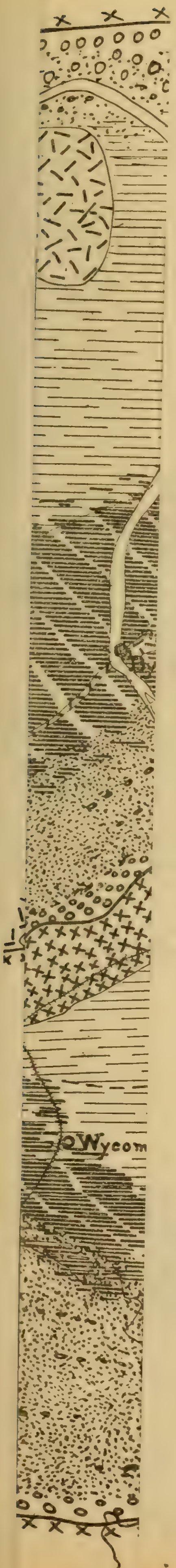

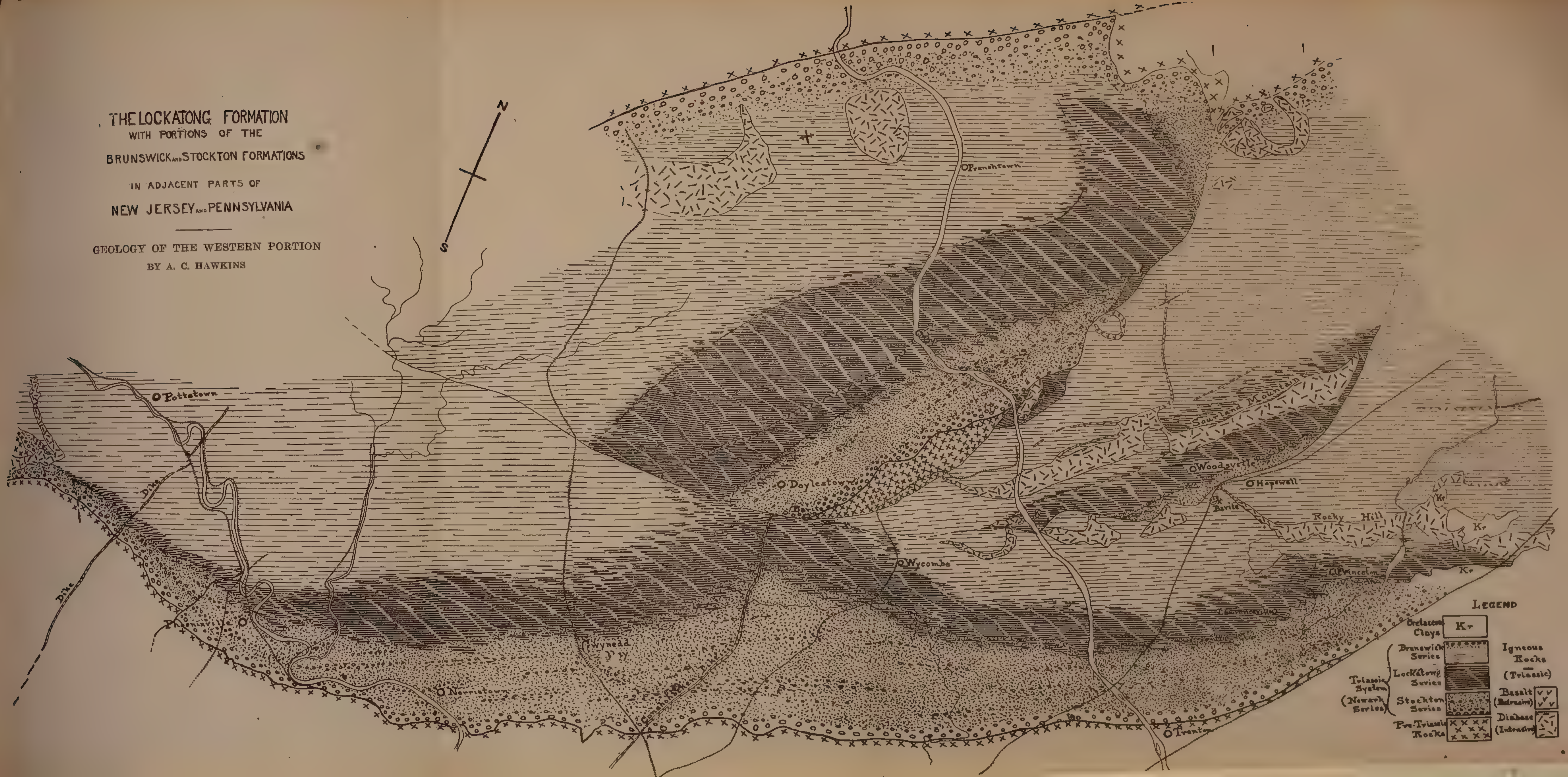
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REVISION OF THE GENUS ZAPHRENTIS

BY

Marjorie O'Connell, A. M.

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REVISION OF THE GENUS *ZAPHRENTIS*

BY MARJORIE O'CONNELL, A. M.

(*Presented by title before the Academy, 1 December, 1913*)

The status of the genus *Zaphrentis* and of two or three allied genera has been the subject of considerable discussion, opinions as to the generic types and descriptions varying widely, and being founded, as a rule, not upon the original descriptions but upon their subsequent interpretations. The study whose results are given in the present communication was undertaken for the purpose of establishing the facts of the case. Original descriptions and figures have in all cases been consulted, and the discussions and synonymies of later writers have been studied and compared. In the older descriptions, which are all in French, it has been necessary for the sake of clearness to introduce modern terminology, but the original French is given throughout in foot-notes so that verification of the translation and of the interpretation is possible.

The genus *Zaphrentis* was first described in 1820 by Rafinesque and Clifford (**1**, 234),[1] the following characters being noted:

> Exterior striated, calyx with straight septa, axis almost central, mamellose, striated excentrically by flexuose lines diverging from an excentric point near a deep, lateral, oblong gap, dorsal, or situated near the convex curvature. The animal must have had a particular organ corresponding to that gap and to the axis of radiation.[2]

Five species are described, namely, *Z. campanula, Z. phrygia, Z. carinata, Z. concava* and *Z. angulata,* all from the Falls of the Ohio, but the descriptions are very indefinite and lacking in detail, and the only form which can be recognized is *Z. phrygia.* This is characterized as

> turbinate, wrinkled; calyx oblique, campanulate, center concave, septa lamellar; base curved, obtuse, entire. A small species resembling a Phrygian bonnet, reversed.[3]

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[1] The first number in the parenthesis refers to the same number in the bibliography at the end of this article, the second to the page references.

[2] "Striée extérieurement, étoile à rayons droits, axe presque central, mamellonné, radié excentriquement par des rayons flexeux divergeant d'un point excentrique près d'un trou oblong, profond, latéral, dorsal ou situé du coté de la courbure convexe. L'animal a dû avoir un organe particulier correspondant à ce trou et à l'axe radié."

[3] "Turbinée, ridée; etoile oblique campanulée, centre concave, rayons lamellaires; base courbée, obtuse, entière.—Petite espèce resemblant à un bonnet phrygien renversé." (**1**, 235.)

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This is a rather meager description and yet it is all there really is for the type of the genus *Zaphrentis*. It must be remembered that methods of study were not as exact then as now, and that generally not all the important characters in a specimen were noted and recorded. The main points recognized by Rafinesque and Clifford are the turbinate, curved corallum; straight septa; external striæ, and the fossula, situated either dorsally or on the convex curvature.

In the same year there appeared in Paris a paper on corals by Lesueur (**2**) in which occurs the following description of a species called *Caryophyllia cornicula:*

> It occurs singly, of a simple form, without the appearance of a base for attachment, horn-shaped, longitudinally striate, with gentle transverse undulations.
>
> Upper extremity broad, with thin edge; calyx more or less concave, septa serrate; two or three inches in length.[4]

Both of these papers seem to have been forgotten for about thirty years, for later authors did not refer to them during that time. Hardouin Michelin in 1840, apparently never having heard of the genus *Zaphrentis*, described a new genus at the Congress of Turin and dedicated it to M. Charles Bonaparte, Prince of Canino, calling it *Caninia*. At this time, no species was mentioned, and it was not until the publication of the "Iconographie Zoophytologique" that we find all the species and figures given. This book is made up of various parts brought out from time to time during the years from 1840 to 1847. Corals from the Carboniferous to the present are described, the whole book being arranged on a geographical rather than a zoölogical plan; that is, for each locality considered, all of the corals are described, and thus we find the four species of *Caninia* treated at different times and in different parts of the book. *Caninia* is first mentioned in the Iconographie in the description of the Sable fauna on page 81 without generic diagnosis, *C. gigantea* being there described. It was not until several years later in the discussion of the Tournay fauna that *C. cornucopiæ* was first figured. (**5**, pl. 59, fig. 5.) Thus one of the mistakes which has long been made as to the type of the genus is accounted for. For the reason that *C. gigantea*[5] is the first species of *Caninia* described in this book, it has by some authors been considered the genotype of *Caninia*, the genus being considered

[4] "Se présente isolée, en tige simple, sans apparance de base pour se fixer, d'une forme corniculée, striée longitudinalement, avec de légères ondulations transverses.

"Extrémité supérieure large, à bord mince; étoile plus ou moins concave, rayons serrés; deux à trois pouces de longueur." (2, 297, 298.)

[5] *Caninia gigantea* of Michelin must not be confounded with *Caryophyllia gigantea* Lesueur, which is entirely distinct and will be considered below.

synonymous with *Zaphrentis*. It was described first, however, merely because Michelin took up the fossils of Sable before those of Tournay, where the other species occur. These three others are *C. cornu-bovis*, *C. patula* and *C. cornucopiæ*, given in the order in which they appear in the "Iconographie Zoophytologique." Carruthers has recently stated (**22**, 159, 166, 168) that *C. cornu-bovis* represents a developmental stage in the ontogeny of *C. cornucopiæ*, being the adult of the latter, and it should, therefore, be included under *C. cornucopiæ* in all synonymies. Carruthers not only studied the original descriptions and figures, but also had the opportunity to examine the type material and many other specimens from Tournay. Nevertheless, if Michelin's figure of the type of *C. cornucopiæ* (Pl. 59, fig. 5) is of natural size, we cannot accept this determination, though we can easily understand that the very young of *C. cornu-bovis* has the character of *C. cornucopiæ*. *C. cornu-bovis* has, however, the adult characters of the genus Siphonophyllia as discussed below. *C. patula*, on the other hand, agrees with *C. cornucopiæ*. If *C. cornu-bovis* were the type of *Caninia*, *Siphonophyllia* would have no generic standing. Lambe and other American authors have selected *C. patula* as the type of *Caninia*, but there seems to be no good ground for this selection. The question, however, is easily settled, for Michelin expressly stated (**4**) that *cornucopiæ* was the type of *Caninia*[6] and he gave the following description:

> Stony polyp, free or fixed, sub-turbinate, simple, cylindrical, formed of superposed cellules (cups) each cell furnished marginally with lamellæ sometimes very short and twisted, sometimes reaching the center, but remarkable in that they can be separated into little conoid funnels representing beyond doubt the succession of the principal vital phases of the polyp, and set one into the other around and forward from the central axis; exterior striated.[7]

This description is composite and fits *C. cornu-bovis* better than it does the other two species; but since the type of the genus was definitely named, the generic characters must be determined by it. These are given in the summary at the end of the paper.

The selecting of *patula* as the type may possibly be explained in the following way: *C. gigantea*, as will be shown below, does not belong to the

[6] "*C. cornu-copiæ*, Mich. Espèce type de genre dédié au prince Ch. Bonaparte."

[7] "Ses caractères sont: polypier pierreux, libre ou fixe, subturbiné, simple, cylindrique, formé de cellules superposées chaque cellule garnie marginalement de lamelles, quelquefois très courtes et sinueuses, quelquefois[8] atteignant le centre, mais remarquable en ce qu'il est décompasable en petits conoids, representant sans doute la succession des principales phases vitales du polype, et s'emboitant les uns dans les autres en dehors et en avant de l'axe central; l'exterieur est strié." (22, 166.)

[8] Introduced by Carruthers for the sake of clearness.

same group as the other species of *Caninia,* but possesses very distinctive characters. The discarding of *C. cornu-bovis* as identical with *C. cornucopiæ* would leave *C. patula* as the first described species in the Iconographie and thus it would become the type. Recognizing the true relations that have just been pointed out, it is evident that *C. patula* must give way to *C. cornucopiæ* as the genotype of *Caninia.*

In 1844 Scouler (**7**, 187) introduced the name *Siphonophyllia* with *Caninia gigantea* Michelin as his genotype, giving as his diagnostic character the peculiar kind of fossula formed by the down-bending and invagination of successive tabulæ. This name, however, has never been used.

Edwards and Haime in 1851 gave a complete discussion of the earlier forms which had been described, and they made *Caryophyllia cornicula* Lesueur the type of *Zaphrentis,* for they found that of the five species of *Zaphrentis* given by Rafinesque and Clifford, *Z. phrygia* was the only one recognizable and this they identified as being the same as Lesueur's *Caryophyllia cornicula.* Since both Rafinesque and Clifford's, and Lesueur's papers appeared in scientific journals in the same year, there is no way of telling from a mere inspection of these volumes which one was published first, but apparently Edwards and Haime consider that Lesueur has precedence. The synonymy for *Zaphrentis cornicula* thus includes *Caryophyllia cornicula* Lesueur, *Zaphrentis phrygia* Rafinesque and Clifford, *Caryophyllia cornicula* Milne Edwards (**3**, 351), *Caninia punctata* D'Orbigny. *Z. cornicula* is described as

a slightly elongated cone, rather strongly curved at the base, especially in young forms, and surrounded by a thin epitheca showing swellings and circular constrictions. Uniform and rather fine ribs can be detected in some individuals, cutting obliquely the dorsal line, which follows the convex curvature. Calyx circular, large and deep; fossula oblong, deep, situated near the convex curvature and prolonged above to form a marked groove. Septa rather regularly radiating. Ordinarily 72 to 92 septa may be counted, alternating and somewhat unequal, strongly serrate, thin, very narrow above, not exert. Their margin divided into projecting points, serrate, scarcely horizontal and largest in the middle of the free portion. The principal septa reach the center of the calyx, where they are covered and slightly raised. In certain individuals, in which the upper tabula is removed, and in which possibly some septa are partly destroyed, a small smooth portion at the center of the tabulæ may be seen. The large examples are 8 centimeters high, the calyx is 5 centimeters in diameter and 3 centimeters deep. Young forms are often found which are only 3 centimeters deep and 2 centimeters in diameter.[9]

[9] "Polypier en cône médiocrement allongé, à base assez fortement arquée, surtout dans le jeune âge, et entouré d'une épithèque mince et présentant quelques bourrelets et quelques étranglements circulaires. On distingue sur quelques individus des cotés égales et assez fines, qui viennent couper obliquement la ligne dorsal qui suit la grande courbure. Calice circulaire, grande et profonde, fossette septale oblongue, profonde, située du coté

Considering Edwards and Haime's synonymy species by species, we find that the description of Lesueur's *Caryophyllia cornicula* agrees with that of *Zaphrentis cornicula* E. and H. so far as it goes, but it contains no reference to a fossula which in *Z. cornicula* is "deep, situated near the convex curvature and prolonged upward to form a very marked groove." (**9**, 327.) In giving the localities where *C. cornicula* is found, Lesueur says that

many rolled forms [*i. e.*, water-worn forms] are found along the borders of Lake Erie, near Eighteen-Mile Creek. The most perfect individuals are enclosed in the most compact banks which also contain the terebratulas [brachiopods].

He adds:

With this species I have found a great quantity of little spherical globules, with spiral striæ, as in the *Gyrogonites* of Europe[10] [a genus of fossil Characeæ]. That, however, could be another species.[11]

He also had specimens from Kentucky which were undoubtedly what are now commonly known as *Zaphrentis* (*Heliophyllum*) *corniculum* and were the same as the *Zaphrentis* of Rafinesque and Clifford, also from Kentucky. As for the Eighteen-Mile Creek forms, the only rugose corals which answer to his description are *Streptelasma* (*Stereolasma*) *rectum*, so far as the form is concerned, and *Heliophyllum halli*, the only carinated species which occurs in great abundance there.

It is quite probable that the Eighteen-Mile Creek forms referred to this species are all *Stereolasma rectum*, which in form closely resembles *Z. corniculum*. The Eighteen-Mile Creek specimens almost never show

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de la grande courbure et se prolongeant en haut sous forme d'une rainure bien marquée. Appareil cloisonnaire assez régulièrement radié. On compte ordinairement de 72 à 92 cloisons alternativement un peu inégales, qui sont très-serrées, minces, fort étroites en haut, non débordantes. Leur bord est divisé en points saillants, serrées, à peu près horizontales et plus grandes sur le milieu de la partie libre. Les principales cloisons arrivent jusqu-au centre de la fossette calicinale, ou elles sont légèrement courbées et un peu relevées. Dans certains individus dont le plancher supérieur est enlevé, et dont peut-être les cloisons ont été partiellement détruites, on voit une petite partie lisse sur le milieu des planchers. Les grands exemplaires ont 8 centimetres de hauteur, le calice est large de 5 et profond de 3. On trouve fréquemment des jeunes qui no sont hauts que de 3 centimètres et larges de 2." (9, 327, 328.)

[10] This is, however, a mistake so far as the Lake Erie shore near Eighteen-Mile Creek is concerned. No such bodies occur there, but they abound with *Z. cornicula* in the Columbus limestone of Ohio. It is quite evident that specimens from both localities were commingled.

[11] "On en rencontre beaucoup de roulés sur le bord du lac Erié, près de dix-huit mille crick. Les individus plus parfaits sont renfermés, dans les bancs les plus compacts, qui font partie de ceux à térébratules.

"Avec cette espèce j'ai rencontré une assez grande quantité de petits globules sphériques, avec des stries en spirale, comme dans la gyrogonite d'Europe. Celle-ci en seroit une autre espèce." (2, 298.)

the septa, and it is quite probable that identification was made by form and size only, the septal characters being taken from Ohio or Kentucky specimens of *Z. cornicula.*

In the Columbus limestone of Ohio the latter are often found associated with the spherical, spirally striated globules *Calcisphæra robusta.* It is thus evident that Lesueur included under his *Caryophyllia cornicula* several species. This was not an uncommon thing for authors to do at that time, when they tried to fit in many quite diverse forms under the already established genera.

Zaphrentis phrygia has already been discussed, but it may be well to add that a number of specimens in the Columbia University collection may readily be identified with *Z. phrygia* as originally described, and they agree perfectly with the description of that species in form, size, fossula and striæ and particularly in the distinctive obtuse angle of the base. The only difference between these specimens and the description is the presence of carinæ, which makes it seem as though, inasmuch as these specimens came from the type locality, Rafinesque and Clifford overlooked, or failed to mention the carinæ, particularly since Edwards and Haime, who probably had the type material before them, make the carinæ one of the characteristics of this species of *Zaphrentis.*

In the second edition of Lamarck, edited by Deshayes and Milne Edwards, the species *Caryophyllia cornicula* of the latter author is described as

simple, corniculate, striate, with transverse undulations dilating toward the apex; calyx concave; septa serrate.[12]

D'Orbigny merely mentions the species *Caninia punctata,* but does not describe it. (8, 105.)

All of those forms, then, are included by Edwards and Haime under *Zaphrentis cornicula.* It is interesting to note that although *cornicula* is the type for *Zaphrentis,* it is now usually accepted as one of the most common forms of *Heliophyllum* and was described as *H. corniculum* by Hall in 1882 as follows:

"Corallum simple, turbinate, regularly curved, acute at the base, rapidly expanding; exterior with shallow constrictions; the surface usually comparatively smooth; on well preserved specimens the costæ are prominent; height usually from thirty to thirty-five millimeters, diameter from twenty to twenty-five millimeters, though examples have been found seventy millimeters in height and forty-five millimeters in diameter; one calyx of twenty-five millimeters diameter has a depth of fifteen millimeters; the sides descend regularly

[12] "C. fossilis simplex, corniculata, striata, transversim undulata, ad apicem dilata; stella concava; lamellis dentatis." (3, 351.)

and abruptly, leaving at the bottom a flattened area about fifteen millimeters in diameter; fossette commencing just posterior to the center and continuing to the posterior margin, much more prominent on the bottom of the calyx; the larger lamellæ continue to the center, slightly twisted; from six to eighteen denticulations in the space of five millimeters; near the margins of the cup they are thin and somewhat obscure, on the sides they are very prominent and spiniform. . . . Although usually placed in the genus *Zaphrentis*, this form presents the characteristics of the genus *Heliophyllum*." (17, 311, 12.)

To the genera *Zaphrentis* and *Caninia* was added a third, *Heterophrentis*, by Billings in 1872, to include the species *spatiosa, excellens, prolifica* and others which were formerly placed under the genus *Zaphrentis*. The type is *spatiosa,* described as follows:

"Corallum simple, turbinate. Calice large, with a well-defined septal fossette, the bottom either smooth or with a pseudocolumella. Septa below the calice sharp-edged, often with their inner edges twisted together; above the floor of the calice they are usually rounded, especially on approaching the margin. There is apparently only a single transverse diaphragm, and this forms the floor of the cup." (12, 236.)

Lambe comments on this genus in his description of *Streptelasma prolificum,* saying,

"The writer is inclined to believe that the species *Heterophrentis spatiosa*, Billings, is founded on short and unusually widely expanding specimens of *S. prolificum.* The two type specimens are from Rama's Farm, Port Colborne, Ontario. Mr. Billings was doubtful as to the validity of the species and concluded the original description with the remark that it is "closely related to *Z. prolifica*, and may perhaps be united with it when its characters become more fully known." (21, 117.)

Furthermore, Billings states that

"It is difficult, perhaps impossible, to decide whether this group of forms is specifically distinct from *H. excellens.* The greatest difference is seen in the surface characters. In *H. excellens* the folds of growth are in general numerous and angular, although some are rounded. In *H. prolifica* they are in general few and nearly always rounded. In *H. excellens* I have only been able to make out the septal striæ distinctly in one specimen. At 1 inch from the base there are 5 and at 2½ inches 4, in the width of 3 lines. In *H. prolifica* there are 8 to 10 at 1 inch, and 6 to 8 at 2½ inches." (12, 237.)

Since Billings was not certain of the specific distinction of *H. spatiosa* and *H. excellens* and considered them as probably only forms of *H. prolifica,* the description of which follows, this latter form then becomes the type of *Heterophrentis*.

Heterophrentis prolifica Bill.

Billings' emended description, 1874:

"Corallum simple, turbinate, curved, expanding to a width of from 18 to 24 lines in a length of from 2 to 4 inches. Surface with a few undulations of growth. Septal striæ 8 to 10 near the base and 6 to 8 in the upper part in a width of 3 lines. Septa from about 100 to 120 at the margin (where they are all rounded), most common number from 100 to 110. In general they alternate in size at the margin; the small ones becoming obsolete on approaching the bottom of the calice; the large ones more elevated and sharp-edged. The septal fossette is large and deep, of a pyriform shape, gradually enlarging from the outer wall inwards for one-third, or a little more of the diameter of the coral, at the bottom of the calice. Its inner extremity is usually broadly rounded or, sometimes, straitish, in the middle. It cuts off the inner edges of from 8 to 12 of the principal septa which may be seen descending into it to various lengths. The surface layer of the bottom of the cup extends the whole width, bending downwards a little near the margin, as in *Zaphrentis*, and uniting with the inner wall of the cup all around. It thus seems to represent one of the tabulæ of a *Zaphrentis*. The following are the principal variations observed in this part of the fossil.

"1. Specimens with a perfectly smooth space in the bottom of the cup; no columella.

"2. A smooth space with a small conical tubercle near the center.

"3. Smooth with a small ridge, two lines in length and half a line in height and width.

"4. Smooth with a compressed columella 3 lines in length, 2 lines in height, most elevated next to the fossette, gradually declining in height towards the opposite side.

"5. Smooth spaces very small, columella a low ridge, with a few tubercles on its crest.

"6. Columella well developed, but with tubercles on it and around it.

"7. Septa reaching the columella and more or less corrugated and either with or without a columella.

"In all cases where the columella is elongated, its length extends in a direction from the fossette to the opposite side. In those which have the septa extending to the centre the columella is often represented by a low rounded elevation." (12, 236, 237.)

In 1900 George B. Simpson published a preliminary description of new genera of Palæozoic rugose corals, in which he includes several species formerly referred to *Zaphrentis*. He erected the genus *Hapsiphyllum* for such zaphrentoid corals, which like *Z. calcariformis* Hall of the St. Louis beds, the genotype, have a horse-shoe shaped inner wall, formed originally by the bending over and uniting of the ends of the septa. The cardinal septum and fossula lie within the area thus enclosed. Another genus made by him is *Triplophyllum* with *Zaphrentis terebrata* Hall as the genotype, and *Z. centralis,* E. and H. and *Z. dalii,* E. and H. as other examples. These species differ from normal *Zaphrentis* and *Heterophrentis* in having the septal arrangement arrested in the primitive quadripartite manner characteristic of the young of rugose corals generally. Thus two lateral or alar pseudo-fossulæ are retained. There are no denticulations or carinæ on the thickened septa. The genera are Devonian and Mississippian in age.

A third generic term proposed by Simpson is *Scenophyllum,* with *Zaphrentis conigera* Rominger as the genotype. This, however, has no close relationship to other zaphrentoids. Finally, he proposed the genus *Homalophyllum* for such species as *Zaphrentis ungula* Rominger and *Zaphrentis herzeri* Hall, which are flattened on the side of greatest curvature. It is not at present certain that the two species named are congeneric, in spite of this flattening on one side.

There has been little discussion of these genera during recent years, until in 1908 Carruthers published a paper entitled "A Revision of Some Carboniferous Corals," in which he especially considers the standing of the genus *Caninia.* He went to the sources in the literature, and after carefully examining not only many specimens of *Caninia cornucopiæ* and allied forms, but also several hundred from the type locality, Tournay, and numerous examples from the Bristol area, he gives a re-definition of the genus as follows:

"*Corallum* simple, turbinate and conical, often slender and cylindrical for a great part of its length.

"*Major septa* well developed and meeting in the centre in the lower, conical part of the coral, but in the cylindrical portions usually becoming amplexoid in character.

"*Minor septa* of various lengths in different species.

"*Cardinal fossula* variable in extent, characteristically limited by tabulæ only, at the inner end, and with flanking septa loose or disconnected.

"*Tabulæ* well developed, but variable in regularity; they may be highly arched and vesicular. A marginal ring of more or less vertical *dissepiments,* usually thin and delicate, intervenes in the mature stages of growth between the tabulæ and the wall." (22, 158.)

In this definition he includes species of the type of *C. cornu-bovis,* which he considered identical with *C. cornucopiæ.*

The most recent paper on *Caninia* is that of Achille Salée, "Contribution a l'Etude des Polypiers du Calcaire Carbonifère de la Belgique," published in 1910. Much of his discussion is based on Carruthers' work and he gives no synonymy, merely referring to that given by Carruthers. His paper, however, is comprehensive and brings out many points not previously emphasized. He states the differences between *Caninia,* in which he includes *Siphonophyllia*, and forms which have been confused with it as follows:

It differs from *Zaphrentis* [including *Siphonophrentis* as defined below, and *Heterophrentis*] by the following characters:

1. The fossula of *Zaphrentis* is limited at the center of the calyx by a regular border, formed by the union toward the interior of the larger septa nearest the cardinal septum, and the tabular depression of the fossula is always extremely deep.

2. Even in the adult, *Zaphrentis* does not have the external vesicular zone, even in a reduced condition.

3. In *Zaphrentis*, there is a stereoplasmic band adhering to the epitheca, while in *Caninia*, that stereoplasmic band detaches itself from the epitheca to form an internal wall; that wall is separated from the epitheca by the external vesicular zone.[13]

The wall is not a true one as in the case of Eridophyllum and Craspedophyllum, but only a pseudotheca. The author continues:

Caninia differs from *Cyathophyllum* in the following characters:

1. The fossula in *Cyathophyllum* is simply indicated, if not absent; radial symmetry is altogether dominant.

2. The vesicular dissepiments affect in *Cyathophyllum* a regularity which is never attained in *Caninia*.

3. In *Cyathophyllum*, there is not a very decided separation between the external vesicular zone and the middle zone. The striking character which gives to the middle zone the stereoplasmic thickening of the septa is lacking in *Caninia*.

4. In *Cyathophyllum* the tabulæ are very near together and are united by many transverse lamellæ, so that they become an irregular mass of rather large vesicles.[14]

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[13] "Il diffère de *Zaphrentis* par les caractères suivants (pl. ix, fig. 1, 2):

"1. La fossette des *Zaphrentis* est limitée au centre du polypier par une bordure régulière, formée par la réunion vers l'intérieur des septa majeurs les plus voisins du septum cardinal, et la dépression tabulaire de la fossette est toujours extrêmement profonde;

"2. même à l'âge adulte, les *Zaphrentis* n'ont pas de zone vésiculaire externe, même reduit;

"3. chez les *Zaphrentis*, il y a une bande stéréoplasmique collée à l'épithèque tandis que chez *Caninia*, cette bande stéréoplasmique se détache de l'épithèque pour former une muraille interne; cette muraille interne est separée de l'épithèque par la zone vésiculaire externe." (24, 13.)

[14] "*Caninia* diffère de *Cyathophyllum* par les caractères suivants (pl. ix, fig. 3 et 4):

"1°. la fossette chez *Cyathophyllum* est simplement indiquée, si pas absente; la symmétrie radiaire est tout à fait dominant;

"2°. les vésicules dissepimentales affectent chez *Cyathophyllum* une régularité qui n'est jamais atteinte dans *Caninia*;

"3°. chez *Cyathophyllum*, il n'y a pas de séparation bien tranchée entre la zone vésiculaire externe et la zone moyenne. La caractère frappant que donne à la zone moyenne l'epaississment stéréoplasmique des septa chez *Caninia* fait ici défaut;

"4°. chez *Cyathophyllum* les planchers sont très rapprochés et réunis par le multiples traverses, de sorte qu'ils deviennent un amas irrégulier de vésicules assez large." 24, 15, 16.)

The species *Caninia gigantea* Michelin, which Salée includes in his revision of the genus as a true *Caninia*, does not seem to fit in with the typical *Caninia* (*C. cornucopiæ*), inasmuch as its fossula is formed not by the meeting of the septa and the abortion of the cardinal septum, but rather by the down-bending of the successive tabulæ to form a series of invaginated funnels, upon which characteristic Scouler based his genus *Siphonophyllia*, making *C. gigantea* Michelin the genotype. This down-bending of the tabulæ forms not a true fossula, which is due to the abortion of the cardinal septum (**23**, 48), but a peculiar type which may be designated a "siphonofossula," and which may or may not be accompanied by an abortion of the cardinal septum. Moreover, *Caninia gigantea* cannot be included under *Zaphrentis*, as typified by *Z. cornicula*, although Edwards and Haime considered it as such, changing the name to *Z. cylindrica* in order to distinguish it from Lesueur's *Caryophyllia gigantea*, which is commonly regarded as a typical *Zaphrentis* in the usual use of the term. Thomson and Nicholson tentatively referred this species to *Cyathophyllum*, because it has the tabulæ restricted to the central area, and has a well-marked circumferential zone of lenticular cells, but still it differs from *Cyathophyllum* in the possession of this pronounced and unique siphonofossula. The name *Cyathophyllum giganteum* was given only temporarily until further restrictions should be made. With the more precise definition of the genera, *Caninia gigantea* Michelin, cannot be placed under either *Caninia* or *Zaphrentis*, but should be left as the type of the genus *Siphonophyllia* which must be reinstated. Lesueur's species of *Caryophyllia gigantea* was found in Kentucky and described in 1820. This is the form commonly known as *Zaphrentis gigantea* (Lesueur). That it cannot be placed in the same genus with *Z. cornicula*, the genotype of *Zaphrentis*, is evident, for it differs from the typical *Zaphrentis* in having the tabulæ well developed, numerous, extending entirely across the visceral chamber and bending down marginally. There is no external vesicular zone, in which respect it agrees with true *Zaphrentis*. On the other hand, the fossula is formed in the same manner as in *Siphonophyllia gigantea* (Mich.) and is really a siphonofossula, the cardinal septum being visible throughout the entire individual. Since both *Caninia gigantea* and *"Caryophyllia" gigantea* have this siphon-like pseudofossula, and since both species are distinct and yet are generically misplaced, Scouler's genus *Siphonophyllia*, which he originally based on the former species as the genotype should be revived with that species as type, while the name *Siphonophrentis* may be adopted for the other species, *Caryophyllia gigantea* Lesueur being the genotype.

In looking over this rather confused array of facts and opinions, it is evident that much of the inexactness in the use of generic terms is due to carelessness on the part of authors in consulting original descriptions and often to their not consulting them at all. This is particularly the case with forms referred to *Zaphrentis*. There is a prevailing idea about the character of this coral, but it seems to have arisen from the opinions expressed by various authors as to what they considered the characters should be, and not from a study of the original description and figures. For instance, Thomson and Nicholson have restricted the genus *Zaphrentis,* stating that it can be recognized

"by the complete, or comparatively complete, development of the septal system, the great development of the tabulæ, the existence of a fossula, which is formed by the coalescence centrally of a certain number of the septa, and the fact that the dissepiments are in no case sufficiently developed to form an exterior zone of vesicular tissue." (14, 428.)

Carruthers in his discussion of *Zaphrentis* bases his generic description upon that given by Thomson and Nicholson, adding that the description "does not pretend to be founded on the specimens from which the original diagnosis was prepared," but "it undoubtedly represents the genus as understood at the present time." He retains the "conventional definition" and Salée, two years later, follows Carruthers. Thus authors have been satisfied to take somebody else's interpretations, instead of going to the sources.

The last genus to be separated from *Zaphrentis* is *Heliophrentis,* described in 1910 by A. W. Grabau (**25**, 98), with *H. alternata* Grabau from the Upper Monroe as the genotype. This is a carinate species closely related to and congeneric with *Zaphrentis racinensis* Whitfield of the Niagara. These species may be congeneric with *Zaphrentis cornicula,* and hence belong to the true *Zaphrentis,* but at present nothing but the form and calicinal structure is known.

I. Briefly reviewed, the facts are these: the genus *Zaphrentis,* first described by Rafinesque and Clifford, was found by Edwards and Haime, who probably had the type material, to contain only one recognizable species and that was *Z. phrygia.* This they considered the same as *Caryophyllia cornicula* Lesueur, described from the same locality and horizon, and called by them *Zaphrentis cornicula.* Since they gave the first full and detailed description as well as figures, this species then becomes the virtual type of *Zaphrentis.* The distinguishing characteristics of the genus are as follows:

Simple, elongated corallum, surrounded completely by an epitheca; deep calyx; a single, well-developed fossula, marking the abortion of the cardinal septum; no columella; numerous, well-developed, serrate septa with carinæ in typical species; tabulæ imperfect or absent; the septa prolonged generally to the center of the visceral chamber.

The forms such as *gigantea, prolifica,* and many others which are commonly considered as *Zaphrentis,* actually do not come under that genus at all and consequently other generic terms must be sought. About contemporaneously with *Zaphrentis* appeared Lesueur's *Caryophyllia cornicula,* characterized by its simple, horn-shaped form, deep calyx, serrate septa, and surface striæ. This is the form which Edwards and Haime identified with *Zaphrentis phrygia* and made the type of that genus. Later Hall placed *cornicula* under *Heliophyllum,* mainly on account of its well-developed carinæ. Since the carinæ are such an important feature in the type species, they cannot be omitted from later generic descriptions, though more primitive species may be without them. Many of the figures of Edwards and Haime's species show the carinæ clearly as in their Plate VI, figs. 1, 1*a,* 1*c,* 1*d.*

II. The next generic name appearing in the historical development is *Caninia* Michelin. *C. cornucopiæ* has been definitely figured and described as the type. It includes those curved forms with deep normal fossula, numerous septa and tabulæ, external striæ and no carinæ, which are at present included under *Zaphrentis.*

III. In 1872 Billings restricted certain species of *Zaphrentis* to *Heterophrentis,* with *H. prolifica* as the type and having at most a single tabula at the base of the calyx, a marked fossula, frequently a columella or a low rounded elevation; septa generally alternating in size, the smaller ones becoming obsolete as they approach the center, the larger ones becoming elevated, sharp-edged and sometimes twisted. This may be extended so as to include species with few tabulæ such as *Zaphrentis simplex* Hall.

IV. The name *Siphonophyllia* of Scouler is revived for forms like *Caninia gigantea* Michelin; *i. e., Zaphrentis cylindrica* of Edwards and Haime, which have numerous tabulæ, a siphonofossula and a well-marked external vesicular zone.

V. Simpson in 1900 proposed *Hapsiphyllum* for zaphrentoids, with a horseshoe-shaped inner wall, making *Zaphrentis calcareformis* Hall the genotype.

VI. Simpson also proposed *Triplophyllum* for forms which, like *Zaphrentis terebrata* Hall and others, retained the alar pseudo-fossulæ.

VII. For zaphrentoids flattened on the side of greatest curvature Simpson proposed the generic name *Homalophyllum,* with *Z. ungula* Rominger as the genotype.

VIII. Grabau in 1910 proposed *Heliophrentis* for Silurian zaphrentoids characterized by carinæ. This may turn out to be synonymous with *Zaphrentis sens str.*

IX. Finally, the term *Siphonophrentis* is here proposed for those forms which like *gigantea* of Lesueur have numerous, well-developed tabulæ extending entirely across the visceral chamber, bending down marginally, and, on either side of the cardinal septum, forming a series of invaginated funnels giving a siphonofossula. There is no external vesicular zone. The name *Caryophyllia* has a definite, restricted sense among modern authors and cannot, therefore, be applied to the forms just characterized. *Siphonophrentis* has for its genotype *Caryophyllia gigantea* Lesueur, the form usually referred to as *Zaphrentis gigantea* from the Middle Devonian of eastern North America. In this as in the preceding genus, the tabulæ are the chief element, the septa being reduced.

Summary of the Revision of the Genus Zaphrentis

Zaphrentis

(*sens. lat.*)

I. **Zaphrentis** Raf. and Clifford *sens str.* Silurian ? to Devonian.
Genotype: *Caryophyllia cornicula* Lesueur.

II. **Caninia** Michelin. Devonian to Mississippian.
Genotype: *Caninia cornucopiæ* Michelin. Other example, *C. patula* Mich.

III. **Heterophrentis** Billings. Silurian ? to Devonian.
Genotype: *Zaphrentis prolifica* Billings. Other example, *Z. simplex* Hall.

IV. **Siphonophyllia** Scouler. Mississippian to Carboniferous.
Genotype: *Caninia gigantea* Michelin. Other example, *C. cornu-bovis* Mich.

V. **Hapsiphyllum** Simpson. Mississippian.
Genotype. *Zaphrentis calcareformis* Hall.

VI. **Triplophyllum** Simpson. Devonian to Mississippian.
Genotype: *Zaphrentis terebrata* Hall. Other examples, *Z. centralis,* E. & H., *Z. dalii,* E. & H.

VII. **Homalophyllum** Simpson. Devonian.
Genotype: *Zaphrentis ungula* Rominger. Other example, *Z. herzeri* Hall (?).

VIII. **Heliophrentis** Grabau. Silurian to Devonian.
Genotype: *H. alternata* Grabau. Other example, *Zaphrentis racinensis* Whitfield (may be true *Zaphrentis*).

IX. **Siphonophrentis** O'Connell. Devonian.
Genotype: *Caryophyllia gigantea* Lesueur (*Zaphrentis gigantea* of most authors).

BIBLIOGRAPHY.

1. 1820. Rafinesque, C. S., and Clifford, J. D.: Prôdrome d'une Monographie des Turbinolies Fossiles du Kentucky (dans l'Amerique septentrionale). Annales Generales des Sciences Physiques, Bruxelles, t. V, pp. 234, 235.
2. 1820. Lesueur, M.: "Description de pleusieurs Animaux appartenant aux Polypiers Lamellifères de M. l. Ch. de Lamarck." Mémoires du Museum d'Histoire Naturelle, Paris, t. VI, pp. 296-298.
3. 1836. Milne Edwards in Annotations de la 2e edition de Lamarck Histoire Naturelle des Animaux sans Vertébres, t. II, p. 351.
4. 1840. Michelin, Hardouin: In P. Gervais: article on "Astræa," Dictionnaire des Sciences Naturelles, Supplement I, p. 485.
5. 1840–1847. Michelin, Hardouin: Iconographie Zoophytologique.
6. 1842. De Koninck, L.: Description des Animaux Fossiles du Terrain Carbonifère de Belgique, pp. 20, 21, 22, pl. C, fig. 4 *a, b, c, d, e, f, g*.
7. 1844. M'Coy: Synopsis of the Carboniferous Fossils of Ireland, p. 187, pl. xxvii, fig. 5. (Description of species by Scouler.)
8. 1850. D'Orbigny, Alcide: Prôdrome de Paléontologie stratigraphique, t. I, p. 105.
9. 1851. Edwards, Milne, and Haime, J.: Monographie des Polypiers fossiles des terrains paléozoiques, Archiv du Museum, Paris, Vol. V.
10. 1860. Milne Edwards, H.: Histoire Naturelle des Corallaires ou Polypes Proprement dits, t. III, pp. 332-347.
11. 1872. De Koninck, L.: Nouvelles Recherches sur Animaux Fossiles de Terraine Carbonifère de la Belgique, p. 100, pl. x, figs. 5, 5*b*; pl. xv, fig. 2.
12. 1872. Billings, E.: "On Some New or Little Known Fossils from the Silurian and Devonian Rocks of Ontario." Canadian Naturalist, new series, Vol. VII, pp. 230-240.
13. 1875. Nicholson, H. A.: Paleontology of Ohio, Vol. VII.
14. 1875. Thomson, James, and Nicholson, H. Alleyne: Contributions to the Chief Generic Types of the Paleozoic Corals. Annals and Magazine of Natural History, 4th series, Vol. XVI, pp. 305-309, 424-429, pl. xii; Vol. XVII, pp. 60-69, pls. vi, vii.
15. 1876. Hall, James: Illustrations of Devonian Fossils.
16. 1876. Rominger, Carl: Paleontology of the Lower Peninsula of Michigan, Vol. III.
17. 1883. Hall, James: 12th Report of the State Geologist of Indiana.
18. 1898–1899. Grabau, Amadeus W.: "Geology and Palæontology of Eighteen Mile Creek." Bulletin, Buffalo Society of Natural Sciences, Vol. VI.

19. 1890. Worthen, Amos H.: Geological Survey of Illinois, Vol. VIII, p. 72, pl. ix, figs. I, I*a*; pl. x, figs. 13, 13*a*.

20. 1900. Simpson, George B.: Preliminary Descriptions of New Genera of Paleozoic Rugose Corals. Bulletin of the New York State Museum, No. 39, Vol. 8, pp. 199-222.

21. 1901. Lambe, Lawrence M.: Contributions to Canadian Palæontology, Vol. IV, pt. ii, p. 117.

22. 1908. Carruthers, R. G.: "A Revision of Some Carboniferous Corals." Geological Magazine, Decade 5, No. 5, pp. 20-31, 63-74, 158-171, pls. 4, 5, 6.

23. 1909. Grabau, Amadeus W., and Shimer, Hervey W.: North American Index Fossils, Vol. I.

24. 1910. Salée, Achille: Contribution a L'Étude des Polpiers du Calcaire Carbonifère de la Belgique.

25. 1910. Grabau, A. W.: Description of Monroe Fossils. Michigan Geological and Biological Survey. Geological Series No. 1. The Monroe Formation, pp. 87-210, plates VIII to XXXII.

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THE MANHATTAN SCHIST OF SOUTHEASTERN NEW YORK STATE AND ITS ASSOCIATED IGNEOUS ROCKS

BY

Charles Reinhard Fettke

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THE MANHATTAN SCHIST OF SOUTHEASTERN NEW YORK STATE AND ITS ASSOCIATED IGNEOUS ROCKS [1]

BY CHARLES REINHARD FETTKE

(Presented by title before the Academy, 1 December, 1913)

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[1] Manuscript received by the Editor, 1 December, 1913.

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Introduction

The Manhattan schist is the uppermost or youngest of the three crystalline metamorphic formations which constitute the bedrock over the southeastern portion of New York State. The other two are the Inwood limestone and Fordham gneiss. These three formations are well exposed at numerous localities in New York, Westchester and the southern portions of Putnam Counties. The overlying mantle of Glacial drift, seldom very thick, has been removed over many portions of the area by erosion and in other places was never laid down. To the north, in Putnam and Dutchess Counties, the upper two formations, the Inwood limestone and the Manhattan schist, are not present, since a belt of gneisses constituting the Highlands of the Hudson intervenes. These gneisses are probably the equivalent of at least a portion of the Fordham gneiss of the region to the south. The overlying formations have here been removed by erosion. North of this belt a quartzite appears resting unconformably upon the gneiss. It is followed by a limestone and a slate.

The oldest of these formations exposed in southeastern New York State, the Fordham, is a black and gray banded gneiss made up largely of quartz, feldspar and biotite, with occasional grains of zircon and a very little apatite and titanite. Hornblende is occasionally abundant. Garnet is rare. The feldspar consists mostly of microcline and orthoclase, together with some albite-oligoclase. The rock shows a typical gneissoid structure, the alternate light and dark bands, which rarely exceed one or two inches in thickness, being due to the concentration of the mica along certain bands. A few thin beds of highly crystalline limestone are found associated with the gneiss. Dr. Charles P. Berkey[2] was the first to call attention to the fact that these are an integral part of the formation. The presence of interbedded limestone indicates the sedimentary origin of at least a portion of this formation. Dr. Berkey has shown that a further subdivision of these basal gneisses is impracticable. He correlates them with the Grenville series of the Adirondacks and Canada, which are known to be of pre-Cambrian age. Associated with them are a large number of igneous intrusive masses whose composition varies from that of granite to that of diorite. Most of these intrusives have also been subjected to metamorphic agencies so that they now appear as gneisses.

A quartzite occasionally appears in the upper portions of the Fordham gneiss to which the name Lowerre has been given, since it is from that

[2] "Structural and stratigraphic features of the basal gneisses of the Highlands." N. Y. State Mus. Bull. 107, pp. 361-371. 1907.

locality just north of the New York City limits that it was first described. This quartzite can be studied well at Sparta, a mile south of Ossining along the New York Central Railroad tracks, and also just east of Hastings-on-Hudson. It seldom exceeds one hundred feet in thickness and apparently grades into the underlying gneiss. None of the outcrops can be followed for any considerable distance laterally and they are not of common occurrence.

The Inwood limestone follows the Fordham gneiss, but in some localities a thin bed of quartzite intervenes, as is mentioned above. Typically, this limestone is rather coarse-grained and crystalline, reaching a maximum thickness of about eight hundred feet. Locally, where the original limestone was impure, tremolite and diopside occur in it and certain beds are quite micaceous, containing large amounts of phlogopite. Much of it runs high in magnesia and grades into a dolomite, but comparatively pure limestone beds are also present.

The exact nature of the contact of this limestone with the underlying gneiss affords a problem which is difficult to solve. Apparently, the bedding planes of the limestone are parallel to the banded structure of the gneiss, and, if this banded structure represents the stratification planes of former sediments from which the gneiss was derived, it would appear that no marked unconformity exists between the two. This relationship has been particularly well brought out by the contacts in the tunnels of the Catskill aqueduct across the formations. In the tunnel underneath the Harlem River just below High Bridge, no deviation from parallelism in the banding of the gneiss and the bedding of the overlying limestone at the contact, which is a sharp one, could be detected. No quartzite is present here, but a thin seam of pegmatite occurs along the contact. It seems that a slight amount of faulting movement has taken place along the contact, which would naturally be a weak zone, but no brecciation could be detected. A short distance beyond this contact, a bed of light gray gneiss several feet thick was encountered in the limestone. Its foliation is also parallel to the bedding of the limestone.

Under the microscope (Pl. XII, Fig. 1), this gneiss is seen to be made up largely of feldspar, quartz and mica. The feldspar is largely microcline, with some orthoclase and plagioclase present. Biotite is the most prominent mica present, only a little muscovite appearing now and then. The biotite is a deep brown variety showing intense pleochroism from light yellow to deep brown. Occasional minute rounded grains of zircon and isolated calcite crystals were noticed. The mica shows more or less parallel orientation, thus giving the rock its gneissoid structure, while the feldspar and quartz occur in interlocking grains of medium texture and uniform size.

The contacts of this gneiss with the limestone are quite sharp, but nevertheless it can only be interpreted as a recrystallized interbedded clastic sediment apparently of about the composition of an arkose.

The underlying Fordham gneiss has a light gray color and a distinctly gneissoid structure, being made up of a series of alternating light and dark bands. On the hill just east of the Harlem River in this vicinity, it is very intricately folded and contorted. Under the microscope (Pl. XII, Fig. 2), it is seen to be made up largely of feldspar, quartz and mica. The feldspar is mostly microcline, although some orthoclase and plagioclase are also present. The mica is for the most part a deep brown biotite with some muscovite. A little sericite occurs as an alteration product derived from the feldspar. Cataclastic structure is well developed. The feldspar and quartz grains are, therefore, not uniform in size and are usually elongated parallel to the foliation.

The difference in structure between this gneiss and the interbedded one is probably due to the fact that the limestone on either side of the interbedded gneiss protected it from the intense crushing effect of the forces accompanying the dynamic metamorphism which developed the cataclastic structure in the underlying gneiss and, therefore, only simple recrystallization occurred.

The same relation between the underlying gneiss and the limestone was shown in a similar tunnel through these formations near the lower end of Manhattan Island and also in the excavations for the dam at Kensico.[3]

The Inwood limestone is succeeded by the Manhattan schist. This consists essentially of a coarse, quartz-mica-feldspar schist which represents a recrystallized sedimentary rock of more or less argillaceous composition. As would be expected in such a formation, there is considerable variation from place to place and even in the same outcrop. At the contact, the limestone frequently grades into the schist. The beds of schist are also interbedded with the limestone and *vice versa.* Associated with the mica schist are certain other types of rock, some of which are schists, others gneisses, while still others are massive. They are undoubtedly of igneous origin. In composition, they range from very siliceous to very basic types. Their relation to the schist is such that it appears quite evident that they were intruded into it in part previous to, in part during, and in part after the period of metamorphism. It is to a description of the Manhattan schist and its associated igneous rocks that this paper is mainly devoted.

All of these formations have undergone intense metamorphism and have been folded into a series of steep anticlines and synclines, which are

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[3] Oral communication by Dr. Charles P. Berkey.

usually unsymmetrical and frequently are overturned toward the west. The axes of the folds have a general northeast and southwest trend and usually have a gentle pitch toward the southwest. As a result of later planation through erosion, the formations are now exposed in a series of fairly parallel belts running nearly northeast and southwest. The limestone belts on account of their easier erosion are usually carved out by the valleys. Of the other two formations, the Fordham gneiss is the most resistant one, but usually the outcrops of both these formations are marked by ridges. Faulting in two directions, parallel with the folds and across them, has occurred. This has complicated their exposures. The limestone which normally should appear between the schist and gneiss has at times been cut out entirely or else its apparent thickness has been considerably reduced.

Historical Review

Since the region underlain by the Manhattan schist was explored and settled long before the science of geology had begun to attract any attention in this country, we find references made to the local formations as soon as men began the study of geology in North America.

One of the earliest references to the Manhattan Schist appeared in P. Cleveland's "Elementary Treatise on Mineralogy and Geology," which was published in 1816. In it H. H. Hayden called attention to a granite ridge which crossed Manhattan Island, appeared again at Hurlgate on Long Island and then extended into Connecticut. This ridge is now known to have been merely a protruding portion of the Manhattan schist which underlies the greater part of the island. William Maclure's first geological map of the United States appeared in the same volume. He placed the rocks underlying Manhattan Island in his primitive formation.

Among other of the earlier discussions on the geology of southeastern New York is that of Samuel Akerly,[4] who described the formations underlying Manhattan Island and Westchester County in 1820. Akerly recognized granites, gneisses, schists and limestones, all of which he placed in the Primitive formation on account of their crystalline character and absence of fossils.

L. D. Gale[5] in 1839, in his account of the geology of New York County, described the rocks as consisting chiefly of gneisses and associated serpentine, hornblende, primary limestones and anthophyllite rock.

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[4] An essay on the geology of the Hudson River, and the adjacent regions, illustrated by a geological section of the county, from the neighborhood of Sandy Hook, in New Jersey, northward, through the Highlands in New York, towards the Catskill Mountains. New York, 1820.

[5] "Report on the Geology of New York County." Third ann. rept. Geol. Surv. New York, pp. 177-199. 1839.

W. W. Mather, who was working on the geology of the first district comprising the southeastern portion of the State, also began the study of these formations. He published his first article in 1838,[6] and in his final report in 1843[7] on the geology of the first geological district for the New York survey gave the first comprehensive discussion of the geology and relationship of the Poughquag-Wappinger-Hudson River series and the Inwood limestone and Manhattan schist to the south. He traced the gray semi-crystalline limestone and overlapping slate north of the Highlands through their various stages of metamorphism into the white and gray crystalline limestones and mica schist to the east. The more crystalline Inwood limestone and overlying Manhattan mica schist with associated hornblende schist and granite intrusions to the south of the Highlands, he considered the equivalent of the above series, but in a more highly metamorphosed phase.

Another paper published about this time, dealing with the geology of a portion of this region, is one by Issachar Cozzens[8] on the geological history of Manhattan Island. He divides the formations of the island into the following series: Granite, syenite, serpentine, gneiss, hornblende slate, quartz rock occurring as veins, primitive limestone and diluvium. A map accompanying the report shows the distribution of these different formations. The relationship of the formations to one another is indicated by a number of cross-sections. Cozzens conceived the island to be underlain by a huge batholith of granite from which the granite dikes radiated out.

In 1867, R. P. Stevens,[9] in his paper on the geology of New York Island, proposed the name "Manhattan Group" for the formations underlying the island which he believed to be the equivalent of Emmons's old Taconic system, now known to represent Cambrian and Ordovician strata that have been highly metamorphosed. Stevens considered the granite dikes which are so numerous on the island to be of metamorphic origin, the same as the gneiss itself. The same applies to the hornblende, anthophyllite and other masses of rock frequently found. He thought that they represented simply different conditions of the same elementary material as the gneiss, which had merely undergone different forms of metamorphism.

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[6] "Report of the geologist of the first geological district of the State of New York." Second ann. rept. Geol. Surv. New York, pp. 121-183. 1838.

[7] Geology of New York, Part I, comprising the geology of the first geological district. Albany, 1843.

[8] A geological history of Manhattan or New York Island, together with a map of the island and a suite of sections, tables, and columns for the study of geology. New York, 1843.

[9] "Report upon the Past and Present History of the Geology of New York Island." Annals N. Y. Lyc. Nat. Hist., Vol. VII, pp. 108-120. 1867.

In 1878, Professor J. S. Newberry[10] stated that it was his opinion that the formations underlying Manhattan Island were Laurentian in age, although he was not in a position to make a positive assertion to that effect. The fact that a mottled serpentine[11] occurs on Manhattan Island which very closely resembles the Moriah marble of the Adirondacks which is known to be of Laurentian age he regarded as very strong evidence of the pre-Cambrian age of the former.

The most important contribution, however, to our knowledge of the formations of southeastern New York State after Mather had published his final report on the first geological district was the result of the work done by Professor James D. Dana in this region during the 70's. In 1880 he published a paper[12] on the geological relations of the limestone belts of Manhattan County. After a careful and detailed study of the limestone belts both to the north and to the south of the Highlands, he came to the conclusion that they were of the same age. He states that the limestones and adjoining schists of Westchester County are younger than the Highland Archean and are probably Ordovician and in part Cambrian in age. He considers that Westchester County was topographically the southern part of the Green Mountain elevation, the axis passing along the Connecticut-New York boundary line and extending through Manhattan Island. He also pointed out that the grade of metamorphism followed the same rule south as north of the Highlands, being of greatest intensity to the south and eastward, since the limestones and associated phyllites northwest of Peekskill were the least metamorphosed of those occurring south of the Highlands, while those of the central and eastern portions of the county and in the western part also were usually very coarsely crystalline. The limestones at Verplanck and Crugers on the other hand have only a moderately crystalline texture. They occupy an intermediate position between the least crystalline and the more coarsely crystalline areas.

James Hall in his report on the building stones of New York State[13] in 1886 followed Dana and correlated the marbles quarried in Westchester County and those of Dutchess County, western Connecticut and Massachusetts and Vermont. He placed them in the Quebec group.

Professor James F. Kemp in a paper on the geology of Manhattan

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[10] "The geological history of New York Islands and Harbor." Pop. Sci. Mthly., Vol. 13, pp. 641-660. 1878.

[11] Trans. N. Y. Acad. Sci., Vol. I, pp. 57-58. 1881-82.

[12] "On the geological relations of the limestone belts of Westchester County, New York." Amer. Jour. Sci., 3rd ser., Vol. 20. 1880. pp. 21-32, 194-220, 359-375, 450-456; Vol. 21, 1881, pp. 425-443; Vol. 22, 1881, pp. 103-119, 313-315, 327-335.

[13] "Report on building stones." 39th ann. rept. N. Y. State Mus. Nat. Hist., pp. 186-225. 1886.

Island[14] in 1887 described the formations underlying the island, with a discussion of their mineralogical composition, origin and structural relationships.

During the late 80's, Dr. F. J. H. Merrill did much field work for the New York State Survey and the United States Geological Survey in the southeastern part of the State both in the Highlands themselves and in the metamorphic area to the south. In his first paper[15] in 1890 on these formations, he describes, under the term "Manhattan Group," the Manhattan schist, Inwood limestone, and Fordham gneiss, and states that he is in doubt as to whether to place this group in the pre-Cambrian or to correlate it with the slates, limestones and quartzites of Ordovician and Cambrian age north of the Highlands. The fact that there is a marked unconformity between the lower Cambrian quartzite and the pre-Cambrian gneiss north of the Highlands and that no such unconformity has yet been found between the Manhattan Group and the underlying beds south of the Highlands would seem strong evidence against such a correlation. On the other hand, he points out that no unconformity has yet been found between the partly metamorphosed strata of Peekskill Hollow, Tompkins Cove and Verplanck's Point, which he considers to be of Ordovician age, and the metamorphic beds of the Manhattan group which adjoin them, although such an unconformity would be expected if the latter are of pre-Cambrian age. In a later report[16] he makes the statement that the two series are equivalent, basing his conclusion on the relation of the quartzite, limestone and schist of Westchester County to the underlying gneiss, as this relation is precisely similar to that of the Paleozoic strata in southern Dutchess County and Putnam County to the subjacent gneiss, and from the nearly complete stratigraphic continuity. This statement apparently is contradictory to the one made in the previous paper quoted, where attention was called to the fact that there was a marked unconformity north of the Highlands, while none such had been found to the south. The Fordham gneiss of the Manhattan group, as previously defined, is considered to be pre-Cambrian in age, possibly Algonkian. The break between it and the Paleozoic is thought to be marked by a stratum of thinly bedded quartzite which crops out occasionally and is followed by the Inwood Limestone.

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[14] "The geology of Manhattan Island." Trans. N. Y. Acad. Sci., Vol. VII, pp. 49-64. 1887.

[15] "On the metamorphic strata of southeastern New York." Am. Jour. Sci., 3rd ser., Vol. XXXIX, pp. 383-392. 1890.

[16] F. J. H. Merrill: "The geology of the crystalline rocks of southeastern New York." 50th ann. rept. N. Y. State Mus., Vol. I, pp. 21-31. 1896.

Merrill's correlation was quite generally accepted as the correct one until 1907, when Dr. Charles P. Berkey[17] published a paper on the basal gneisses of the Highlands, based upon field work done by him in the Tarrytown and West Point quadrangles. He does not accept the correlation of Merrill and others and presents very strong evidence that the Inwood-Manhattan series south of the Highlands and the Poughquag-Wappinger-Hudson River series, to the north, are not equivalent. According to his position there are then the following six formations in relative order from the top downward overlying the basal gneisses:

(6) Hudson River phyllite or slate, which is very thick.
(5) Wappinger fine-grained blue and white banded limestone, about one thousand feet thick.
(4) Poughquag fine-grained quartzite, three hundred to six hundred feet thick.
(3) Manhattan coarsely crystalline mica schist, which is very thick.
(2) Inwood coarsely crystalline limestone, two hundred to eight hundred feet thick.
(1) Lowerre thin schistose quartzite, zero to one hundred feet thick.

The Lowerre quartzite south of the Highlands is closely related to the underlying gneiss, whenever it appears, which is not very frequently. It is thin when it does occur, rarely exceeding one hundred feet in thickness, and is always conformable with the associated gneiss. The Poughquag quartzite north of the Highlands on the other hand is usually much thicker, three hundred to six hundred feet, and rests with a marked unconformity upon the underlying gneiss. The relationship of these formations in the region northeast of Peekskill in the Peekskill Creek and Sprout Brook Valleys led Dr. Berkey to conclude that the two series could not be regarded as the same in age. The quartzite-limestone-phyllite series of the Peekskill Valley section he considers to belong to the Poughquag-Wappinger-Hudson River group, representing a down-faulted block of these once overlying formations into the older strata. A mile to the northwest across a ridge another belt of limestone occurs in the Sprout Brook Valley. This limestone is coarsely crystalline in contrast with the finely crystalline limestone of the Peekskill Creek section and contains silicate minerals and pegmatite intrusions which are absent in the latter. No quartzite whatever occurs in either margin of it, while the Peekskill Creek limestone has five hundred feet of quartzite conformably beneath it. The limestones of these two valleys can hardly be considered the same, and, if the Sprout Brook limestone is the equivalent of the Inwood, as Dr. Berkey thinks, the less metamorphosed Peekskill Creek limestone is

[17] "Structure and stratigraphic features of the basal gneisses of the Highlands." N. Y. State Mus. Bull. 107, pp. 361-378. 1907.

clearly shown to be of later age and the Inwood limestone-Manhattan schist series cannot be the equivalent of the Wappinger limestone-Hudson River slate series, represented here, but must be of earlier age and hence pre-Cambrian.

There are, therefore, at present two contrasting views: first, that the Inwood limestone and Manhattan schist series is of Cambro-Ordovician age, as held by Merrill, Dana, Mather and others; and second that it is of pre-Cambrian age, as held by Dr. Berkey. The present writer has made a rather detailed study of the Manhattan schist and its associated rocks as developed in the southeastern portion of the State of New York south of Highlands and has compared it with the Hudson River slates, phyllites and schists north of the Highlands to see what light such a study might throw on the problem from a petrographic standpoint. Typical localities were studied in detail and most of the areas of schist exposed were visited. A detailed structural study, however, involving very careful geologic mapping of large portions of the area underlain by these formations was not attempted.

Manhattan Schist

AREAL DISTRIBUTION

The Manhattan schist is exposed in a series of fairly broad, roughly parallel belts having a general northeast-southwest trend in the region south of the Highlands of the Hudson and east of the Hudson River (see map, Pl. XV). West of the Hudson River the Newark formation of Jura-Triassic age has concealed them with the exception of a small area in the vicinity of Tompkins Cove just south of the Highlands. The belted nature of the outcrops of this and the underlying formations, as has already been explained, is due to the erosion of a series of anticlines and synclines whose axes have a northeast-southwest trend. The schist occurs as far north as the southern portion of Putnam County in this area. Farther north the rest of Putnam and the southern portion of Dutchess County are underlain by the older gneisses of the Highlands, the younger formations having been entirely removed by erosion. The use of the term "Manhattan" has been confined entirely to those schists which make up the uppermost or youngest of the bedrock formations occurring in southeastern New York State in New York, Westchester and Putnam Counties. In Connecticut the continuation of the schists has been described under the name of "Berkshire," as given to them by the Connecticut Geological Survey.[18]

[18] Conn. Geol. and Nat. Hist. Surv. Bull. No. 6, pp. 91-92. 1906.

PETROLOGY

The Manhattan schist as typically developed on Manhattan Island consists chiefly of a dark coarsely crystalline mica schist. In a hand specimen biotite, muscovite, quartz, feldspar and some garnet can usually be recognized. The relative amounts of these different minerals in a particular specimen will vary greatly from place to place. In some cases, the micas greatly predominate over the other constituents, and the rock often shows a crenulated structure where it has undergone intense folding and crumbling. Often considerable amounts of feldspar are present, but in other cases, this constituent is almost entirely absent. Garnet is also more abundant in one place than another. In occasional seams, the rock is made up largely of quartz and feldspar with only a little mica in small flakes. The rock takes on a gray color and is less coarsely crystalline, the structure becoming gneissoid rather than schistose. Some of these grade almost into a quartzite, as the amount of feldspar present grows less. On Manhattan Island, however, the micaceous varieties are greatly in excess over the others.

A thin section made from a typical specimen of the micaceous variety taken from the site of the Journalism Building of Columbia University, at the southeast corner of West 116th Street and Broadway, shows under the microscope a coarsely crystalline texture and marked foliated structure (Pl. XIII, Fig. 1). The chief minerals present are biotite, muscovite, feldspar, garnet and a little quartz. Magnetite is fairly abundant and small amounts of pyrite are also present. Several grains of staurolite have been noticed. The biotite is a dark greenish-brown, intensely pleochroic variety. It is practically always oriented with its basal plane in the plane of schistosity, to which cause the foliation of the schist is principally due. Muscovite is not nearly as prominent as the biotite. It is often intergrown with it and shows a similar orientation in the plane of foliation. The space between the micas is occupied by the feldspar and quartz. The outlines of these minerals are quite irregular and they are closely interlocked. They are usually quite free from inclusions. Plagioclase is the most abundant feldspar present, although some orthoclase also occurs. The plagioclase is optically positive and belongs to the andesine variety. It has a maximum extinction angle of 20° in sections cut perpendicular to the albite lamellæ. The garnet is a light pink variety occurring usually in idiomorphic crystals which reach a diameter of 1.4 millimeters. Analysis 1 quoted in a later paragraph gives the chemical composition of this specimen.

A thin section of the light gray gneissic variety from Shaft 18 of the Catskill Aqueduct at West 42nd Street near Fifth Avenue, where it occurs in a belt about two feet wide interbedded with the typical micaceous type, on the other hand shows a medium-grained crystalline texture and only slightly foliated structure (Pl. XIII, Fig. 2). The principal constituent minerals are quartz, feldspar and biotite. Apatite is present in appreciable amounts in minute lath-shaped crystals. The feldspar consists of both orthoclase and plagioclase. The latter has a maximum extinction angle of 22° in sections at right angles to the albite lamellæ and is optically positive. It is evidently andesine. Both the quartz and the feldspar occur in allotriomorphic, interlocking grains. The biotite is a dark greenish brown, intensely pleochroic variety. The chemical composition of this type of schist is given under analysis 2 on page 212.

Closely related to the gray gneissoid variety just described is a type occasionally found in which the amount of feldspar is very small, the predominant mineral being quartz, so that the rock practically becomes a quartzite. A section of a specimen from West 155th Street and Tenth Avenue shows a medium-grained crystalline texture and slightly foliated structure. The rock is made up largely of quartz with some feldspar and biotite. Magnetite and a little apatite are also present. The biotite occurs in small, usually irregular flakes whose basal sections are oriented parallel to the plane of foliation. It shows marked pleochroism from light greenish yellow to deep greenish brown. The quartz and feldspar occur in allotriomorphic, closely interlocking grains. The feldspar consists of both orthoclase and plagioclase. The latter shows extinction angles up to 8° in sections at right angles to the albite lamellæ and is probably oligoclase.

Another variety which has a comparatively fine crystalline texture and shows only moderate foliation has the biotite occurring in numerous small flakes showing parallel orientation in a matrix of quartz and feldspar. The rock has a dark color. A specimen collected two and one-half miles north of New Rochelle along the Westchester Railroad when examined in thin section under the microscope shows the rock to consist mostly of quartz, biotite and feldspar and minor amounts of pyrite, magnetite and apatite. The biotite is a dark reddish brown variety showing intense pleochroism from light yellowish brown to deep reddish brown. The quartz and feldspar occur in allotriomorphic, interlocking grains. Both orthoclase and plagioclase feldspar are present, the latter giving extinction angles running as high as 39° in sections at right angles to the albite lamellæ. This would indicate labradorite.

The schist in the vicinity of New Rochelle and northeast of that point becomes for the most part very feldspathic in composition and takes on a gneissoid structure. A thin section from a specimen collected east of Pelhamville shows a medium-grained crystalline texture and foliated structure. The principal minerals are feldspar and quartz in allotriomorphic, interlocking grains, together with smaller amounts of biotite and muscovite. A little apatite is present as needle-like inclusions in the feldspar and quartz. An occasional grain of zoisite, a little magnetite and a few rounded grains of zircon also occur. The feldspar which is the most abundant mineral present consists of both orthoclase and plagioclase. The plagioclase is an andesine variety, being optically positive and showing extinction angles up to 10° in sections at right angles to the albite lamellæ. The biotite occurs in small flakes whose basal sections are in the plane of foliation. It shows marked pleochroism from light brownish yellow to deep brown.

Farther northeast, in the vicinity of Rye, most of the Manhattan schist formation becomes very quartzose in composition. Alternating with the thicker beds of quartzitic schist are thinner seams which are more micaceous and hence show foliation to a much more marked degree. The quartzitic schist has a light gray color and a medium-grained texture. Examination under the microscope shows that it is made up largely of irregular interlocking grains of quartz and minor amounts of feldspar, mostly plagioclase of an oligoclase-albite variety, giving extinction angles up to 8° in sections at right angles to the albite lamellæ and being optically positive. Some biotite of a deep greenish brown variety and a little muscovite are also present. A few minute rounded grains of zircon may be seen.

A gneissoid to schistose quartz-mica-feldspar rock probably belonging to the Manhattan schist formation occurs in the east central portion of Westchester County. It has been considered a part of this formation by F. J. H. Merrill[19] in mapping the lower Hudson sheet for the New York State Survey and also by Edson S. Bastin,[20] who examined the pegmatites occurring in it at Bedford Village. Lea M. Luquer and Heinrich Ries,[21] who have also made a study of the area, on the other hand consider it a part of the Fordham. The writer's studies in this region were not sufficiently detailed to allow him to make a positive statement, but it seems most likely from the position of these rocks with respect to surrounding limestone belts, outcrops of which occur occasionally and which are

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[19] Geologic map of New York. Lower Hudson Sheet. N. Y. State Mus.

[20] Bull. 315, U. S. Geol. Surv., pp. 344-399. 1906.

[21] "The 'Augen' gneiss area, pegmatite veins and diorite dikes at Bedford, N. Y." Am. Geol., Vol. XVIII, pp. 239-261. 1896.

undoubtedly a part of the Inwood, that these schists are a part of the Manhattan formation.

A specimen collected one-half mile southeast of Bedford Village along the road to Stamford, when examined under the microscope in thin section, shows a medium-grained crystalline texture and foliated structure. The principal minerals present are quartz, feldspar and biotite. Pyrite and magnetite occur in minor amounts. The feldspar consists of both orthoclase and plagioclase, the latter showing extinction angles up to 30° in sections at right angles to the albite lamellæ. It is probably an acid labradorite variety. The feldspar and quartz occur in irregular, fairly even-sized, interlocking grains. The biotite occurs oriented parallel to the plane of foliation and shows intense pleochroism from light yellowish to dark reddish brown. Another specimen collected one mile northwest of Poundridge shows very little variation in texture, structure or mineralogical composition from the above. The plagioclase here shows extinction angles up to 22° 30′ and is evidently andesine. A light pink garnet containing numerous inclusions of quartz and biotite is present in considerable amounts.

From the above description it will be seen that the rock is lithologically very similar to certain types of Manhattan schist occurring quite abundantly elsewhere. In this schist, however, southeast of Bedford Village, large "augen" of feldspar, usually orthoclase, which reach a length of one inch or more at times, are locally quite abundant, so that the rock becomes an "augen" gneiss. A further discussion of these "augen" will be taken up under pegmatitic intrusions in a later paragraph.

With the exception of the above occurrence of "augen" gneiss at Bedford Village, the schist does not show any petrographic feature essentially different from those already described from Manhattan Island and the region immediately to the northwest, until an outcrop occurring just north of Croton-on-the-Hudson is reached. Following north from this point along the road to Peekskill one crosses an area of the schist which is less thoroughly metamorphosed than most of the schists of the same age occurring to the south and also than those occurring one and one-half miles further north, in the vicinity of the Cortland intrusions which will be discussed later.

Just north of Croton Village, along the above road, the schist has a dark gray color and very foliated structure. In a hand specimen, it appears to be made up largely of prominent crystals of biotite imbedded in a fine shiny matrix consisting mostly of muscovite. Under the microscope, the most prominent mineral is seen to be biotite (Pl. XIII, Fig. 4). It is a deep reddish brown variety showing marked pleochroism and usually has its basal section oriented parallel to the plane of foliation but not always. The fine-textured matrix in which the biotite occurs consists of muscovite, smaller biotite flakes, quartz and iron oxides. The little flakes of muscovite and biotite are usually oriented parallel to the foliation and often curve around the larger biotite crystals.

Going north from the above locality the schist seems to show slightly more severe metamorphism. Garnet and in some cases staurolite become important mineral constituents. Tourmaline has been introduced. A specimen collected about one mile north of Croton-on-the-Hudson along the road is made up largely of a matrix of fine muscovite in which numerous garnet and staurolite crystals are imbedded. Under the microscope, the matrix is seen to be made up largely of small flakes of muscovite together with some quartz and a little orthoclase and plagioclase (Pl. XIII, Fig. 5). Most of the biotite present occurs in much larger flakes than the muscovite. A light pink garnet and a yellowish brown staurolite are quite abundant, occurring in idiomorphic crystals. For a chemical analysis of this schist see analysis 3 on page 212. This was the only place south of the Highlands where staurolite was found as an abundant constituent in the schist. It is only present elsewhere in very small amounts. The rock here has a little more coarse-grained crystalline texture than that described above.

Another specimen taken from near the same locality shows upon examination in thin section under the microscope abundant little lath-shaped crystals of dark brown tourmaline. The rock is also much more quartzose and feldspathic. The feldspar is largely plagioclase of an andesine variety, showing extinction angles up to 25° in sections measured at right angles to the albite lamellæ.

North of this area, no schist is again encountered until the southern margin of the Cortland intrusive series is reached. A belt of gneiss and limestone intervenes. A specimen of the mica schist from a point one-quarter mile west of Crugers, not far from the river and a short distance south of the contact with the diorites of the Cortland series, is seen, under the microscope, to be made up of biotite, muscovite, quartz and garnet, associated with small quantities of orthoclase and plagioclase and a little apatite. The biotite shows marked pleochroism from light yellowish brown to deep brown. It and the muscovite are often intimately intergrown with their basal sections in the plane of foliation. The irregular interlocking quartz grains are also usually elongated parallel to the schistosity. The garnet is very abundant in small crystals, rarely exceeding a diameter of .2 millimeter.

The schist northeast of Crugers along the railroad near the contact shows very much the same structure and mineralogical composition. Feldspar, mostly orthoclase, is most abundant. Some of the quartz is filled with inclusions of rutile needles. Garnet is not as abundant, but it occurs in somewhat larger grains.

Farther north, an area of schist and limestone undoubtedly belonging to the Manhattan-Inwood series adjoins the Cortland intrusives on the west at Verplanck. The schist here has a medium to fine crystalline texture and a banded rather gneissoid appearance. In thin section under the microscope, it is seen to consist largely of mica, mostly biotite, although considerable amounts of muscovite, feldspar and quartz (Pl. XIII, Fig. 3) are also present. Minor amounts of a dark brown tourmaline also occur. The biotite shows intense pleochroism from light yellowish brown to deep brown. The feldspar is mostly microcline, which is present in large amounts. The structure is distinctly foliated, due to the parallel orientation of the mica and the elongation of the feldspar and quartz grains.

Another specimen of mica schist which occurs interbedded with the limestone at Verplanck, when examined under the microscope, proves to be much less thoroughly recrystallized and metamorphosed than the above. Abundant irregular flakes of deep brown biotite occur in a very fine-grained matrix consisting mostly of quartz and sericite.

The schist again appears just north of the Cortlandt intrusive rocks. Not far from the actual contact near the southeastern corner of the town of Peekskill, several outcrops occur along the road to Yorktown Heights. The rock is medium to fine grained in texture and distinctly foliated. Under the microscope, it is seen to be made up largely of biotite, sericite and quartz. The quartz grains occurring between the parallel mica flakes are extremely fine in texture. Another specimen taken from a point nearer to the actual contact is much more crystalline in its nature and shows a higher degree of metamorphism. The minerals present are biotite, muscovite, quartz, feldspar, staurolite, garnet and a little sillimanite. Some dark brown intensely pleochroic tourmaline was also noticed.

North of this area, no further outcrops of true schists belonging to the Manhattan formation occur, but along the northwestern side of the Peekskill Creek Valley about two miles northeast of Peekskill a phyllite appears. A description of this phyllite and a discussion of its relation to the Manhattan formation will be taken up in a later paragraph.

East and southeast of Peekskill the schists representing the Manhattan formation become coarsely crystalline again and are more nearly like those occurring on Manhattan Island. In places a quartzitic variety predominates. This is made up largely of quartz, with some feldspar, biotite and muscovite and a little garnet. Some magnetite is also present. The quartz and feldspar occur in irregular interlocking grains, while the micas are oriented parallel to the foliation. Both orthoclase and plagioclase are present. The plagioclase shows extinction angles up to 9° in sections at right angles to the albite lamellæ and is evidently a variety of oligoclase. The garnet occurs in irregular grains at times full of quartz inclusions. Thin seams of very micaceous type are often interbedded with this quartzitic variety of schist. These are usually very much crenulated and contorted, while the quartzitic variety does not show these minor folds. This micaceous type consists largely of muscovite and biotite, with small amounts of quartz and a little garnet. The mica flakes curve around the garnet.

Toward the northeast, the most northerly outcrops of Manhattan schist occur in the vicinity of Brewster in southeastern Putnam County. Schists and limestones belonging to the Manhattan-Inwood series are well exposed in a cut about two miles east of Brewster along the New York and New England Railroad. The schist is rather coarsely crystalline and has a distinctly foliated structure. In thin section under the microscope, it is seen to consist principally of feldspar, biotite and quartz, together with a little tremolite, pyrite and an occasional rounded zircon grain. The feldspar is mostly plagioclase giving extinction angles up to 24° in sections at right angles to the albite lamellæ. It is probably an acid labradorite. Some orthoclase is also present, since many of the feldspars are unstriated and optically negative. The biotite shows marked pleochroism from light yellowish to deep reddish brown. The rock has undergone considerable strain. Most of the feldspar shows strain shadows and wedge twins are common. Mortar structure is also developed in the case of some of the feldspar grains, which are frequently surrounded by a border of finely granular material.

About one mile south of Brewster along the road to Croton Falls a quartzite phase of the schist is well developed. The rock here is made up of quartz, biotite, feldspar and muscovite, with quartz greatly in excess of the other constituents. Occasionally a light pink garnet is also present. The quartz is quite free from inclusions. It and the feldspar occur in interlocking grains usually elongated parallel to the foliation. The biotite is a dark greenish brown, highly pleochroic variety. More micaceous and feldspathic phases of the schist are also present at this locality, but the quartzitic type predominates. On the whole, however, the schist in the vicinity of Brewster is very closely similar to that occurring farther south.

The relation of the Manhattan schist to the underlying limestone is well shown in the excavation at present being made for the new Kensico reservoir dam at Valhalla about two miles north of White Plains in southern Westchester County. The Fordham gneiss, Inwood limestone, and Manhattan schist occur in their normal order of succession here, the gneiss making up the hills on the east, while the schist makes up those on the west of the reservoir site, with the limestone occupying the valley between the two. The formations all dip steeply toward the west.

A thin section of the Fordham gneiss taken from near the contact with the overlying limestone shows a distinctly gneissoid structure. It is made up largely of feldspar, biotite and quartz, together with a little titanite and an occasional apatite crystal. The feldspar is largely plagioclase, giving extinction angles up to 8° in sections at right angles to the albite lamellæ. It is optically positive and is evidently an oligoclase-albite variety. The biotite is an intensely pleochroic, deep brown variety. It occurs in comparatively small crystals. The greater concentration of these in particular bands gives the rock its gneissoid appearance.

In the limestone, a short distance above the contact with the underlying gneiss, an interbedded layer of gneissoid rock several feet thick occurs. Under the microscope, it is seen to be made up largely of feldspar, both microcline and orthoclase, diopside, a reddish brown variety of biotite, calcite and a little quartz. Minor quantities of titanite were also noticed.

As the contact of the limestone with the overlying schist is approached, layers of interbedded schist begin to appear in the limestone. Some of these are quite garnetiferous. A thin section of a garnetiferous mica schist occurring at this point, when examined under the microscope, was seen to consist largely of biotite, garnet, quartz, sillimanite and a little feldspar, both orthoclase and plagioclase being represented. A few rounded grains of zircon are also present. The garnet, which occasionally contains inclusions of magnetite and biotite, is a light pink variety and reaches a diameter of .5 millimeter. The sillimanite occurs in little needles in the quartz and also as a fibrous aggregate. It is abundant. The biotite is a deep reddish brown variety. The rock contains numerous small stringers of pegmatitic material. For its chemical composition see analysis 4 on page 212. Other varieties of the interbedded schist contain little or no garnet and are made up largely of a deep reddish brown biotite, quartz and feldspar, mainly orthoclase. A few small rounded grains of zircon are usually present.

The limestone adjoining these layers of interbedded schist is often impure, at times grading into an ophicalcite. A thin section of such an ophicalcite was found to consist essentially of calcite, serpentine and muscovite. The structure of the serpentine shows that it was derived from a mineral belonging to the olivine group. One piece was found in which a few small cores of the original olivine were still left unaltered. It proved to be optically negative and, therefore, must either be true olivine, with more than 12 per cent iron, or else the variety monticellite ($Mg\ Ca\ SiO_4$).

It was absolutely colorless. The serpentine to which it has altered is also colorless in thin section and grass green in the hand specimen. No other minerals occur which would indicate the presence of much iron in the original sediment from which the ophicalcite was derived, as for example, phlogopite or biotite. Therefore, it appears probable that the original mineral was monticellite.

The true Manhattan schist overlying the limestone at this point is a feldspathic micaceous variety of medium gray color. Under the microscope, it is seen to consist largely of biotite, muscovite, quartz, feldspar, mostly orthoclase, sillimanite and a little garnet. A few small rounded grains of zircon are also present. The rock has undergone considerable crushing here since the original recrystallization during metamorphism took place. This is shown by the nature of the broken quartz and feldspar crystals and to a less extent the mica. The mica also often occurs in bent crystals.

Another variation in the schist observed, especially in the southern portion of the area on Manhattan Island, and not heretofore described, appears in the form of occasional bands very rich in cyanite. These seldom reach a width of more than an inch or two, and wherever observed were parallel to the schistosity. At times, these bands are made up entirely of long prismatic crystals of cyanite associated with muscovite and quartz (Pl. XII, Fig. 3). These crystals are optically negative and show elongation parallel to the slow ray. Extinction is unsymmetrical. Their long axes are parallel to the schistosity. These bands grade into the mica schist in which the cyanite occurs associated with biotite, muscovite, some garnet and only a little quartz. Thin veinlets of introduced quartz are usually associated with the bands running parallel to the foliation. A chemical analysis of this schist is given in a later paragraph under analysis 5 on page 212.

STRUCTURAL FEATURES

The schist and underlying formations, as has already been mentioned in the introduction, occur in a series of rather closely folded anticlines and synclines usually unsymmetrical and often overturned toward the west. The axes of these folds run in a general northeast and southwest direction and in many cases have a gentle dip toward the south. In addition to these major folds, many minor folds are developed in the schist, so that at times it becomes exceedingly contorted and crinkled. As is usually the case in folded rocks of this nature, the axes of these minor folds are parallel to those of the major ones.

Most of the schist, especially the more micaceous varieties, shows a marked foliated structure. In the case of the more gneissoid varieties, this may not be so marked, but a more or less banded structure can always be made out.

As has already been pointed out in the petrographic description, the schist shows considerable variation from place to place and even in the same outcrop. Different varieties may grade into one another gradually, or the transition may be fairly abrupt. In either case, the schistosity is always parallel to the bands of varying composition.

The schist and underlying limestone, as shown by the description already given, grade into one another, and the layers of schist interbedded with the limestone near the contact have a strike and dip which are parallel to that of the actual contact of the overlying Manhattan schist with the limestone. The foliation of the schist near the contact is parallel to the bedding of the limestone.

The normal relationship of the schist to the underlying beds has frequently been obscured by faulting. In general, these faults have a strike approximately parallel to the axes of the folds, and when such is the case, the schist may be brought in contact with the gneiss, as frequently happens. East and west faults nearly at right angles to the axes of the folds also occur. Joints are well developed in the schist at many places. A nearly vertical set cutting across the folds at about right angles is well developed at several localities on Manhattan Island.

CHEMICAL COMPOSITION

The following analyses of various types of Manhattan schist made by the writer show the range in chemical composition of some of the different varieties present:

Analyses of Manhattan Schist

	1	2	3	4	5
SiO_2	46.50	68.51	50.90	45.03	74.14
Al_2O_3	24.97	15.68	30.46	33.76	23.82
Fe_2O_3	2.63	.71	1.36	None	.63
FeO	9.58	2.32	4.59	8.19	.46
MgO	3.70	1.42	1.09	2.75	.19
CaO	2.27	3.83	.93	1.85	None
Na_2O	3.55	4.62	1.96	2.22	.37
K_2O	4.34	2.49	6.86	4.62	.52
$H_2O +$	.82	.13	.49	.91	.52
$H_2O -$	.07	.01	.05	.16	.02
TiO_2	1.61	.57	1.54	1.28	.08
Total	100.04	100.29	100.23	100.77	100.75

1. Mica feldspar schist from southeast corner of Broadway and West 116th Street, New York.
2. Gray gneissoid variety from Shaft 18, Catskill Aqueduct, West 42nd Street, near Fifth Avenue, New York.
3. Staurolite mica schist north of Croton-on-the-Hudson.
4. Garnetiferous mica schist, Kensico.
5. Cyanite schist, West 120th Street, east of Amsterdam Avenue, New York.

An examination of these analyses brings out several interesting features. In all of these, except No. 2, the MgO is present in excess over the CaO and the K_2O over the Na_2O. Also the ratio of Al_2O_3 to the CaO, Na_2O and K_2O exceeds the 1 : 1 ratio in each of these cases. In No. 1, this excess amounts to 70 per cent; in No. 3, 147 per cent, and in No. 4, 181 per cent. In the case of No. 5, no comparison is necessary, as the amounts of K_2O and Na_2O present are practically negligible and CaO is absent entirely, while the rock contains 23.82 per cent of Al_2O_3. Such a relationship as the above could only exist in a rock which was originally of sedimentary origin.[22] The analyses, therefore, give an important clue as to the origin of these schists.

ORIGIN

As shown above, the analyses of various types of mica schist belonging to the Manhattan formation, with the possible exception of No. 2, indicate a sedimentary origin for this formation. Analysis No. 1 of the typical mica feldspar-quartz schist developed on Manhattan Island corresponds to that of a rather argillaceous shale. The same holds true for Nos. 3 and 4. No. 2, on the other hand, which is that of a gray gneissoid variety, as far as chemical composition is concerned, might be either of sedimentary or igneous origin. Its field relation, however, to the associated typical mica schist is such that it can only be interpreted as being of the same origin and merely representing a phase of deposition of somewhat different character. The clastic material from which it was derived, originating from the disintegration of an igneous rock of granitic composition, had probably been less thoroughly decomposed and sorted before deposition took place, therefore giving rise to the deposition of an arkose. It probably represents a coarser phase of deposition than any of the others which originally were undoubtedly fine muds.

The variation in texture and composition of the schist both vertically and horizontally over large areas also permits of but one interpretation, namely, a sedimentary origin. The occurrence of occasional very quartzitic beds grading into pure quartzites furnishes further corroboration toward this conclusion. The nature of the contact between the schist and

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[22] Edson S. Bastin: Jour. Geol., Vol. 17, p. 472. 1909.

underlying limestone also agrees with such a view. The gradation of the limestone into schist and the occurrence of thin beds of schist in the limestone near the contact is what one would expect to find when the conditions favorable for the deposition of a limestone gradually changed toward those leading to the deposition of an argillaceous sediment. Evidently the two formations are conformable.

Later, these strata underwent profound regional metamorphism which led to the complete recrystallization of the constituents present. These changes were brought about through burial to a considerable depth underneath other sediments, followed by the inauguration of a period of great orogenic movements which brought about the intense folding of the strata involved. These orogenic movements were accompanied by a series of granitic intrusives which are described later and which also must have been important factors leading toward the thorough recrystallization of the original sediments. Their effect will be discussed in somewhat greater detail in another paragraph.

The formation of the schist, therefore, took place under mass-mechanical conditions in the zone of ana-morphism, as described by Professor Van Hise.[23] If we follow Dr. Grubenmann's plan of dividing the outer portion of the earth into three zones, based upon the nature of the metamorphic changes taking place at different depths, the formation of the schist took place in the middle zone. In this zone, as described by Dr. Grubenmann,[24] the temperature is notably higher than in the upper zone, and pressure and temperature alike tend to work toward the production of such minerals as represent the smallest molecular volumes and highest specific gravities for the constituent components present. The pressure is mostly due to stress, although hydrostatic pressure due to the superincumbent mass also begins to become effected. There is little possibility of any movement of the particles, and stress aided by temperature, therefore, works principally toward recrystallization, so that chemical action not only keeps pace with mechanical but even exceeds it. Wholly crystalline rocks are therefore formed in this zone, and good cataclastic structures are not of common occurrence. On account of the fact that the prevailing pressure is due to stress, this is the home of the schists. The characteristic minerals of this zone are muscovite, biotite, zoisite, epidote and to a lesser extent hornblende, staurolite, garnet and cyanite. Dr. Grubenmann[25] also calls attention to the well known fact that the higher the temperature and pressure under these conditions the greater will be the

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[23] Monograph XLVII, U. S. Geol. Surv., pp. 685-698. 1904.

[24] Die kristallinen Schiefer. Zweite Auflage, p. 78. 1910.

[25] *Ibid.*, p. 75.

tendency of minerals rich in OH to alter to those lower in OH and finally to those free from it entirely. Chlorite will be replaced by biotite; zoisite and epidote by plagioclase, and muscovite, by orthoclase and microcline.

In the case of the Manhattan schist, it has already been seen that the biotite-quartz-feldspar varieties predominate, although muscovite is usually also present and is frequently an important constituent. These evidently represent the final stages to which metamorphism will proceed in this zone. With the exception of the area of schist to the north of Croton-on-the-Hudson and that in the vicinity of Peekskill far enough away from the Cortlandt intrusions to be out of range of very much influence from their contact metamorphic effects, the schists of the region under discussion have all undergone about the same degree of metamorphism.

In the case of the schist just north of Croton Village, it is quite evident that the fine matrix of muscovite, biotite, quartz and iron oxide in which the coarser biotite flakes are imbedded, if recrystallization had proceeded to a further stage, would have been converted into a much coarser mass consisting of larger biotite crystals, feldspars and quartz, with possibly some garnet and only a little muscovite. Further north of the same area of schist where metamorphism has been somewhat more intense, feldspar does become quite prominent. Staurolite and garnet also become quite abundant constituents of the schist here. The garnet, as seen from the petrographic description of the schist from widely distributed outcrops, is a quite common constituent of these rocks. Staurolite, on the other hand, is quite rare, this being the only place south of the Highlands where it was found in any abundance. Apparently with the more severe metamorphism which took place to the east and south, it was converted into other minerals. What has been said in regard to the schist just north of Croton-on-the-Hudson also applies to the schist occurring near the southeast corner of the town of Peekskill along the road to Yorktown Heights.

As may be seen from the petrographic description, the minerals present in the schist are quartz, orthoclase, plagioclase (ranging from oligoclase to labradorite), biotite, muscovite, garnet, staurolite, sillimanite, cyanite, magnetite, pyrite, apatite, zircon, zoisite and tourmaline. Of these, all but the tourmaline have probably resulted from the recrystallization of constituents already present in the original sediments before recrystallization took place. None of these minerals contain components which would not occur in such a formation as the one from which the schist was derived. The presence of the tourmaline on the other hand is probably due to the introduction of a least a portion of its constituents, especially the boron by emanations which accompanied the pegmatitic intrusions referred to later.

The thin seams of cyanite schist described as occasionally occurring in the mica schist on Manhattan Island are sufficiently different from the ordinary mica schist to deserve further mention. Referring back to analysis 5, p. 212, which is of such a schist, it will be seen that it is made up almost entirely of silica and alumina. If this schist had been derived from an original sediment, it would mean that there must have been a very thin layer of practically pure kaolinite and quartz where the thin seams of cyanite schist now occur. As already mentioned, it hardly ever occurs in seams over one or two inches wide. It is not very probable that such a remarkable concentration of these two constituents should occur in such narrow seams when the surrounding sediments were of such entirely different composition. What seems more probable is that some of the more soluble original constituents have been leached out by percolating waters along these seams, leaving behind the less soluble alumina probably present in the form of kaolinite. The stringers of introduced quartz associated with these seams would seem to bear out this theory. They at least indicate that such circulation has taken place. This circulation of water along these seams and the introduction of quartz was probably closely related to the pegmatitic intrusions occurring in the schist which are discussed later.

Associated Igneous Rocks

FOLIATED BASIC INTRUSIONS

Hornblende Schist

Intercalated with the mica schist of the Manhattan formation are often layers of hornblende schist which vary in width from less than a foot up to two hundred feet or more. These layers may often be followed along the strike for several thousand feet. Sometimes several of them will occur parallel to one another and separated by only a slight thickness of intervening mica schist.

The gradation from hornblende to mica schist is always a sharp one. The sheets of hornblende schist practically always occur parallel to the foliation of the schist which has been shown to be parallel to the bedding (Pl. VIII, Fig. 1). The writer did not come across a case where any marked deviation from this relationship could be detected, but Dr. Charles P. Berkey[26] has discovered an occurrence in mapping the geology of the Tarrytown quadrangle where the hornblende schist cut distinctly across the foliation of the mica schist, and Mr. John R. Healy[27] has observed a similar case in the Catskill aqueduct under Manhattan Island.

[26] Oral communication.
[27] Oral communication.

In general, however, as already shown, these sheets run parallel with the foliation of the mica schist and are just as folded and crumpled as the latter. At times, the hornblende schist is even more plicated than the mica schist. This usually occurs where the latter was a rather quartzose variety. In such a case, the hornblende schist is the more pliant member, and naturally it was more closely folded.

In a hand specimen, the hornblende schist appears rather massive, showing some foliation, however, and a tendency to cleave in parallel plates. Its color is greenish black which serves to readily distinguish it from the lighter colored mica schist. In mineral composition, it consists principally of a dark green hornblende, together with subordinate amounts of feldspar, mostly plagioclase, and quartz. Minor accessory constituents usually present are magnetite, biotite, apatite, titanite, zircon and pyrite. In some cases, garnet also occurs in it in quite appreciable amounts. This schist maintains a fairly uniform mineral composition from place to place without much variation in the percentages of the constituents present.

The hornblende schists are particularly well developed along the southern shores of Croton Lake in the vicinity of the old Croton dam. A thin section of a specimen taken from an outcrop exposed in a cut a short distance west of the bridge across the lake at this place when examined under the microscope is seen to consist largely of dark green hornblende, together with minor amounts of quartz and feldspar (Pl. XII, Fig. 4). Titanite is present in considerable amounts. Other accessory minerals are biotite, magnetite, zircon and apatite. The hornblende is a deep brownish green variety showing marked pleochroism from light greenish brown through brownish green to deep green. Prismatic cleavage is well developed. It often contains inclusions of titanite and apatite. The feldspar and quartz occur in irregular interlocking grains of comparatively small size. The feldspar is mostly plagioclase, although some of it is unstriated. It shows extinction angles up to 16° 30′ in sections at right angles to the albite lamellæ and is optically positive. It is evidently andesine. The hornblende crystals show a roughly parallel orientation which gives the rock its foliated structure. The chemical composition of this specimen of hornblende schist is given in a later paragraph.

An interesting phenomenon was noticed along a fault plane which intersected, obliquely to the foliation, the sheet of hornblende schist just described. On both walls of the fault a thin coating consisting of dark greenish brown biotite flakes was developed. Evidently during the shearing accompanying the fault movement conditions were favorable for recrystallization, and the hornblende along the fault was converted into biotite. A little secondary quartz was also introduced. The hornblende schist must still have been buried under a considerable thickness of overlying strata when this took place, as the alteration of hornblende into biotite requires rather deep-seated conditions.[28]

Small stringers of pegmatitic material are fairly numerous in the hornblende schist at this place. These usually follow the foliation of the schist, although at times they also cut across it and occasionally widen out into lenticular or irregular shaped masses. Associated with these stringers are occasionally found lenticular masses of epidote schist evidently derived by alteration from the hornblende schist. These are seldom more than six inches wide and three or four feet long (Pl. VIII, Fig. 2).

In thin section, this variety is seen to consist principally of epidote associated with remnants of the unaltered dark green hornblende. Some calcite is also present as a secondary product. Quartz appears both in little irregular shaped grains distributed through the whole mass and also in little stringers. The accessory constituents present are magnetite, titanite and zircon. A chemical analysis of the epidote schist will be found in a later paragraph. Such a rock is known as an epidosite.

Attention has already been called to the sharp contacts between the hornblende schist and mica schist. This is very noticeable wherever such contacts are exposed. Thin sections of the hornblende schist and mica schist where they adjoin were examined from two parallel hornblende schist sheets occurring in the mica schist about one and one-quarter miles northwest of Hartsdale along the road to Elmsford. The lower of these sheets is about two and a half feet thick, while the upper one is much thicker but is partially covered. Two and one-half feet of mica schist separate the two. They are involved in a sharp anticline.

The mica schist is a quartzitic variety at this place which has a medium-grained crystalline texture and foliated structure. It consists largely of quartz in irregular grains and usually elongated parallel to the foliation; of a dark greenish brown biotite showing parallel orientation and a little feldspar, mostly plagioclase; of an occasional small garnet, and of a few rounded grains of zircon. The hornblende schist is a dark greenish black rock with a more or less foliated texture. It consists principally of a dark brownish green hornblende, together with feldspar and a little quartz. Accessory constituents are magnetite, zircon, titanite and zoisite. The hornblende shows marked pleochroism from light brown through brownish green to dark green. The feldspar is mostly plagioclase, giving extinction angles up to 23° 30′ in sections at right angles to the albite lamellæ, thereby indicating an andesine.

Very little difference from the normal was noticeable in these two rocks in the specimens taken from near the contacts. Occasionally biotite be-

[28] C. R. Van Hise: Treatise on Metamorphism. U. S. Geol. Surv., Mon. 47, p. 290. 1904.

came quite an important accessory constituent of the hornblende schist, but this mineral was present just as abundantly in specimens collected elsewhere, where they were not taken from the vicinity of any contact. In the mica schist, however, just above the lower sheet of hornblende schist, which is the smaller of the two, a dark brownish green hornblende identical with the one present in the hornblende schist was found in occasional crystals. Such a hornblende was not noticed in any other specimens of mica schist and is not a normal constituent of this rock. Apparently the presence of the hornblende schist explains its occurrence.

Closely related to the hornblende schist is a variety of hornblende or quartz diorite gneiss which occurs in the mica schist at various places but not nearly as abundantly as the hornblende schist itself. Its mode of occurrence and structural relationship are the same as that of the hornblende schist, and sometimes it grades into the latter. Megascopically it is seen to be made up of alternating light and dark bands, usually less than an inch thick, which grade into one another.

Such a gneiss occurs about three-quarters of a mile southwest of Millwood along the road to Ossining. The lighter bands, when examined under the microscope, are seen to consist largely of quartz, feldspar and hornblende, together with small amounts of biotite. A little garnet is also present, as well as an occasional zircon. Small amounts of epidote and zoisite occur as secondary minerals. A somewhat cataclastic structure has been developed. The feldspar consists of both orthoclase and plagioclase. The latter is optically positive and shows extinction angles up to 5° 30′ in sections at right angles to the albite lamellæ, which would indicate an albite-oligoclase. The darker bands owe their color to the fact that the hornblende becomes much more abundant in them, being the most important constituent. The other minerals of the lighter bands, however, are also present but in smaller amounts.

Actinolite and Tremolite Schists and Associated Types

Another type of schist occasionally found interstratified with the mica schists consists predominantly of actinolite or tremolite. This type is very similar in its mode of occurrence to the hornblende schist just described. A sheet was encountered in the Catskill Aqueduct tunnel just north of Shaft 18 at Madison Square, New York City. The borders of the sheet consist of a very coarsely crystalline biotite schist, in which biotite makes up the greater part of the rock. Most of the sheet, however, is an extremely foliated tremolite schist. When examined in thin section under the microscope, it is seen to be made up largely of tremolite, biotite and a little talc. The tremolite occurs in long acicular crystals showing good prismatic cleavage. Transverse fractures are also well developed.

The biotite is a deep brown variety with a slight tinge of red. It occurs sparingly throughout the mass between the tremolite crystals and is also concentrated in lenticular bunches averaging about .2 x .3 x 1.00 inch in size. The talc occurs in tabular flakes among the tremolite crystals. In portions of the sheet, the talc predominates and the rock grades into a talc schist. Veins of asbestiform amphibole up to two inches in width have also been developed in places. This amphibole occurs with its long axis at right angles to the foliation. The tremolite occurs in parallel orientation with the schistosity. The whole mass shows evidence of having undergone intense shearing accompanied by recrystallization of the constituent minerals into new combinations.

The mass of actinolite and tremolite schist formerly exposed at Eleventh Avenue and West 59th Street[29] is another example of this type. Here talcose and chloritic varieties, together with serpentine and ophicalcite, were also present in close association with the actinolitic and tremolitic varieties.

Harrison Granodiorite Gneiss

Another rock probably quite closely related genetically to the hornblende schist described is a granodiorite gneiss occurring in the southeastern portion of Westchester County. Its relation to the mica schist is somewhat similar to that of the hornblende schist, only it occurs in a much more extensive mass. The strike of the gneissoid to schistose structure developed in it is parallel to the foliation of the mica schist adjoining it.

This gneiss is most extensively developed just across the State line in Connecticut, where it occupies a large area. Two prongs from this mass extend southwest into Westchester County, New York. The northwestern one of these is about one and one-quarter miles wide and extends as far as Larchmont, while the southeastern one is about one mile wide and extends to Rye Point. An area of schist about one and three-quarter miles wide separated the two prongs.

Professor Heinrich Ries[30] was the first to describe this gneiss from the vicinity of Harrison in Westchester County, and it has since then been generally referred to as the "Harrison granodiorite." The Connecticut Survey[31] on their preliminary geological map of the State, however, have called it the Danbury granodiorite gneiss, correlating it with similar gneisses which are quite extensively developed in other portions of western Connecticut.

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[29] A. A. Julien: "Amphibole schists of Manhattan Island." Bull. Geol. Soc. Am., Vol. 14, pp. 421-494. 1903.

[30] "On a granodiorite near Harrison, Westchester County, N. Y." Trans. N. Y. Acad. Sci., Vol. 14, pp. 80-86. 1895.

[31] Geol. and Nat. Hist. Surv. Conn., Bull. No. 7. 1907.

In a hand specimen, the rock shows a very gneissoid structure and medium coarse crystalline texture. The principal minerals present are biotite, hornblende, feldspar and quartz, with the ferromagnesian minerals occurring in such large amounts as to give the rock a dark color. Occasionally "augen" of feldspar are a prominent feature in the rock. These sometimes reach a length of one inch with a width of one-quarter inch.

A thin section of a specimen from north of Larchmont in Westchester County, when examined under the microscope, shows a medium coarse crystalline texture and foliated structure due to the more or less parallel orientation of the biotite and hornblende. The section consists largely of feldspar, hornblende, biotite and quartz. Magnetite, titanite and apatite are present as accessory constituents. The feldspar is largely plagioclase, which gives extinction angles up to 26° in sections at right angles to the albite lamellæ and is optically positive. It is evidently an acid labradorite. Some orthoclase is also present, much of the feldspar being unstriated. A micrographic intergrowth of feldspar with quartz is occasionally developed. Undulatory extinction in the feldspar and quartz is of common occurrence.

Another thin section made from a specimen from Greenwich, Connecticut, shows practically the same structure and texture (Pl. XII, Fig. 5). The mineral composition varies only slightly. Biotite is present in excess of hornblende. In addition to the plagioclase and orthoclase, some microcline also occurs. An analysis of this rock is given in the next paragraph.

The following analyses of hornblende schist, epidosite and granodiorite gneiss were made by the writer:

Analyses of Hornblende Schist, Epidosite and Gneiss

	1	2	3
SiO_2	45.90	43.52	55.71
Al_2O_3	15.58	16.60	19.15
Fe_2O_3	2.23	6.66	......
FeO	10.48	4.79	5.81
Mgo	7.02	3.42	4.52
CaO	11.14	19.95	6.42
Na_2O	2.47	.77	3.55
K_2O	1.19	.25	4.56
H_2O+	.20	.31	.09
H_2O-	.06	.11	.06
CO_2	......	.41	......
TiO_2	3.71	3.92	.75
Total......	99.98	100.71	100.62

Norms

	1	3
Orthoclase	7.23%	27.24%
Albite	16.77	28.30
Anorthite	27.80	22.52
Nephelite	2.27	1.14
Diopside	22.32	7.55
Olivine	13.08	12.36
Magnetite	3.25	....
Ilmenite	7.08	1.54

No. 1. Hornblende schist from south shore of Croton Lake. Magmatic symbol, III, 4.4.3. Auvergnose.

No. 2. Epidote schist or epidosite from above locality.

No. 3. Granodiorite gneiss. Greenwich, Connecticut. Symbol II, 5.3.3. Shoshonose.

In the following table, analyses of massive igneous rocks very similar in chemical composition to the hornblende schist and granodiorite gneiss are given for comparison:

Analyses of Schists and Massive Igneous Rocks

	1	2	3	4	5	6	7	8
SiO_2	45.90	49.78	47.45	46.59	46.91	55.71	55.69	54.72
Al_2O_3	15.58	13.13	14.83	17.55	15.85	19.15	19.09	17.79
Fe_2O_3	2.23	4.35	2.47	1.68	2.86	......	4.07	2.08
FeO	10.48	11.71	14.71	10.46	9.95	5.81	3.26	6.03
MgO	7.02	5.40	5.00	7.76	7.01	4.52	3.41	5.85
CaO	11.14	8.92	8.87	10.64	9.62	6.42	6.87	6.84
Na_2O	2.47	2.39	2.97	3.31	2.65	3.55	2.89	3.02
K_2O	1.19	1.05	.99	.72	.69	4.56	4.41	3.01
H_2O+	.20	1.14	1.00	.07	1.62	.09	.17	......
H_2O-	.06			.10	.24	.06	......	......
TiO_2	3.71	2.22	1.47	1.41	2.03	.75	......	......
P_2O_5	......	......	......	......	.26	......	......	......
MnO	......	.27	.36	......	.22	......	......	......
CO_2	......	.10	......	......	......	......	......	......
Total	99.98	100.46	100.12	100.29	99.98	100.62	99.85	99.34

No. 1. Hornblende schist from south shore of Croton Lake.
No. 2. Hornblende schist, Scourie, N. W. coast of Scotland. J. J. H. TEALL, Quart. Jour. Geol. Soc., Vol. 41, p. 137. 1885.
No. 3. Dolerite (diabase), Scourie, N. W. coast of Scotland. J. J. H. TEALL, Quart. Jour. Geol. Soc., Vol. 41, p. 135. 1885.
No. 4. Camptonite, Salem Neck, Essex Co., Mass. H. S. WASHINGTON, Jour. Geol., Vol. VII, p. 285. 1899.
No. 5. Diorite, Hump Mountain, Mitchell Co., North Carolina. U. S. Geol. Surv. Bull., p. 52. 1900.
No. 6. Granodiorite gneiss, Greenwich, Connecticut.
No. 7. Biotite vulsinite, Monte Santa Croce, Rocca, Monfina, Italy. H. S. WASHINGTON, Jour. Geol., Vol. V, p. 252. 1897.
No. 8. Gabbro, S. E. corner of Salt Hill, near Peekskill, N.Y. J. F. KEMP, Handbook of Rocks, p. 72, No. 3. 1908.

ORIGIN OF HORNBLENDE SCHIST AND GRANODIORITE GNEISS

Dr. A. A. Julien[32] in a paper on the amphibole schists of Manhattan Island has given an excellent description of these rocks and their mode of occurrence. He has also taken up a detailed discussion in regard to their origin, and his conclusions have been quite generally accepted as being correct. He believes that these rocks represent metamorphosed igneous rocks of rather basic composition which were injected through fissures and spread out parallel to the bedding planes of the mica schist in the form of intrusive sheets or sills at a period prior to the folding of the latter.

The chemical composition of the hornblende schist furnishes very strong evidence in favor of its igneous origin. It is that of a rather basic igneous rock. The three analyses of massive igneous rocks, one of a diabase, another of a camptonite and a third of a diorite, which are given for comparison in a previous paragraph, correspond very closely to that of the hornblende schist. The hornblende schist from Scourie, Scotland, has a texture corresponding very closely to that of the New York hornblende schist. The diabase from Scourie, Scotland, has a diabasic texture. In mineral composition, it consists of feldspar, augite, ilmenite, apatite and small amounts of such secondary products as hornblende, chloritic minerals, quartz and pyrite. The camptonite from Salem Neck, Massachusetts, approaches the ophitic texture. The minerals present are hornblende, less pyroxene, occasional olivine, a labradorite feldspar, a little orthoclase and some magnetite and, rarely, apatite. The diorite from Hump Mountain, North Carolina, contains plagioclase, orthoclase, hornblende and minor amounts of quartz, biotite, magnetite and garnet. It is readily conceivable that rocks of such mineralogical composition upon undergoing intense dynamic metamorphism could and would be converted into hornblende schist. The augite in the case of the diabase and camptonite would naturally be converted into hornblende. Olivine would not be staple under such conditions and, if present, would disappear, entering into the composition of some other ferromagnesian mineral.

Another strong point in favor of an igneous origin for the hornblende schist is the sharp contact always found occurring between it and the mica schist, with the absence of any signs of gradation of one into the other. It has already been pointed out that wherever undoubted sedimentary contacts occur in the district no such sharp contacts are found, as for example, the gradation of limestone into mica schist or one type of mica schist into another.

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[32] Bull. Geol. Soc. Am., Vol. 14, pp. 421-494. 1903.

If any evidence of contact metamorphism could be found, this would still further corroborate the igneous origin of the hornblende schist. As already mentioned, the only occurrence observed by the writer which might indicate such a contact zone was the occasional presence near such a contact of isolated hornblende crystals in the mica schist which were similar in appearance and optical properties to those of the hornblende schist.

The relation of the hornblende schist to the mica schist is such as might readily result from the intrusion of a series of sheets parallel to the bedding of the schist. Such a relation would also result if the igneous rock had been poured out as a lava flow at successive intervals during the period of deposition of the sediments from which the mica schist was derived. This would, however, necessitate the occurrence of numerous periods of igneous activity followed by periods of deposition of fine argillaceous sediments, as the sheets probably occur at various horizons in the schist over practically the whole area under consideration. The same would be true if they represented metamorphosed interbedded basic tuffs. It is much more reasonable to suppose that the igneous rock was intruded at numerous horizons in the sediments after their deposition in the form of intrusive sheets or sills. The fact that the hornblende schist does occasionally cut across the foliation or bedding further corroborates such a view. The only peculiar feature about the hornblende schist, if the above interpretation is correct, is that it has never yet, to the writer's knowledge, been found cutting the Inwood limestone. The probable explanation for this is that the limestone did not part readily along its bedding planes and the intrusive simply passed up through it along fissures which are not at present exposed.

From the foliated structure of the hornblende schist and its relation to the mica schist, it is quite evident that it was intruded into the original sediments prior to the period of folding and regional metamorphism. Both have been folded and crumpled with equal intensity and have been completely recrystallized. They now possess a marked foliated structure and a medium to coarsely crystalline texture. J. J. H. Teall[33] has described a similar hornblende schist from Scourie, on the northwest coast of Scotland, which can be traced through various stages of metamorphism into an original diabase dike. Analyses of this hornblende schist and diabase are quoted in a previous paragraph. The hornblende schist is made up of deep green hornblende, quartz, feldspar, ilmenite, sphene and apatite. The diabase consists of feldspar, augite, ilmenite, apatite and minor secondary products including hornblende, chlorite, quartz and

[33] Quart. Jour. Geol. Soc., Vol. 41, pp. 133-145. 1885.

pyrite. This rock was converted into hornblende schist by mechanical deformation accompanied by molecular rearrangement of the augite and feldspar. The changes which resulted in the formation of the hornblende schist of southeastern New York were probably very similar to those which have occurred in the case of the Scourie dikes.

The lenticular to tabular shaped masses of epidosite occasionally observed in the hornblende schist associated with small stringers of pegmatitic material represent an alteration which has occurred since the development of the foliated structure, since the remnants of unaltered hornblende in the epidosite show the same parallel alignment as those in the normal schist. The hornblende and feldspar of the original hornblende schist along these zones have been converted into epidote. This was brought about by some marked changes in chemical composition, as a comparison of an analysis of the hornblende schist with one of the epidosite developed from it will show. Such analyses are given in a previous paragraph. The change was accompanied by a partial oxidation of the iron and a very noticeable reduction in the percentage of magnesia, it being less than one-half as high as it is in the hornblende schist, with a correspondingly large increase in the amount of lime present. The alkalies almost disappeared during the alteration, while the percentages of the other constituents remained practically the same.

Dr. Julien,[34] in his study of this phase of alteration in the hornblende schist, came to the conclusion that intense local compression and strain were necessary for its development and that it was not connected with the process of change to pegmatite. This alteration does occur along minor fracture zones in the hornblende schist, but where observed by the writer, the injection of pegmatitic materials also accompanied those where alteration to epidote has taken place. It seems more plausible, therefore, to think that the circulation of the solutions which brought about the necessary chemical changes involved in this alteration did accompany the pegmatitic injections which occur in these fractured zones.

The actinolite, tremolite and talc schists occasionally found interstratified with the mica schist, especially on Manhattan Island, are very similar in their mode of occurrence to the hornblende schist just described. They undoubtedly have a similar origin, in that they represent much metamorphosed intrusive sheets of basic igneous rocks. In composition, these intrusives were probably somewhat more basic even than those from which the hornblende schists have been derived, since in order to get a metamorphic rock made up largely of such minerals as actinolite, tremolite and talc, it would be necessary to have an igneous rock high in magnesia and lime and comparatively low in silica, alumina and the alkalies.

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[34] *Op. cit.*, p. 446.

The igneous origin of the Harrison granodiorite gneiss has never been questioned by those who have made a study of this rock. Its chemical composition is clearly that of a medium basic igneous rock, as a comparison with analyses of massive igneous rock of similar composition will show. Its uniformity of texture, structure and mineral composition over large areas is another point in favor of such an origin. It probably entered the older strata in the form of a large irregular laccolith and when they were shales. There was thus a period of igneous activity antedating the folding and dynamic metamorphism of the sediments. We reach this conclusion because of the very marked foliated structure, clearly of secondary origin, which has been developed in the granodiorite. The strike of the foliation is parallel to that of the mica schist which surrounds the intrusive.

MASSIVE BASIC IGNEOUS ROCKS

In addition to the highly metamorphosed foliated basic igneous rocks which occur as intrusives in the Manhattan schist, there is another series which shows only slight or no effects of dynamic metamorphism. The series appears as normal, massive, igneous rocks of basic composition and of granitoid texture intrusive in the schist and as massive serpentine derived from such rocks.

Cortlandt Series

The largest of these intrusive masses of basic igneous rocks occurs just south and east of Peekskill, covering an area of about twenty-eight square miles in the township of Cortlandt, the most northwesterly in Westchester County, from which the series has taken its name.

It consists of an igneous complex made up of a great number of different varieties of intrusive igneous rocks mostly of a basic nature which grade into one another, often by almost imperceptible transitions. G. S. Rogers in a recent paper[35] has discussed the geology of this intrusive mass in detail. He has shown that there is a centrally located norite area flanked on both sides by pyroxenites. The western pyroxenite probably continues beneath the Hudson River, since these rocks outcrop again at Stony Point. Between this western area of pyroxenites and the norites, lies a diorite area. To the extreme northeast, the basic rocks are adjoined by an area of granite. The order of intrusion seems to have been first pyroxenite, followed closely by the norites, the diorite and finally granite. It is among the basic members of the series that gradations from one into another appear, producing a large number of intermediate types.

[35] "Geology of the Cortlandt series and its emery deposits." Ann. N. Y. Acad. Sci., Vol. XXI, pp. 11-86. 1911.

Only slight evidences of dynamic metamorphism are found in the rocks of the Cortlandt series.[36] The degree varies considerably among the different types, the granite showing the least, while in the diorite appreciable effects of strain are at times discernible, although they are rarely sufficient to be perceptible in a hand specimen. These effects are most noticeable in the vicinity of inclusions of mica schist, and it is to the borders of foreign inclusions that the effects of dynamic metamorphism are usually confined. Evidently, therefore, these rocks entered after or at least toward the close of the period of intense folding, during which the shales were converted into mica schists, because, if the intrusion had taken place previous to that period, one should discover a foliated structure similar to that present in the Harrison granodiorite.

Very marked contact metamorphism has frequently occurred in the mica schist in the vicinity of the intrusions. Mention has already been made of this in describing the mica schist in the vicinity of Peekskill and Crugers. G. H. Williams[37] has given an excellent description of a contact zone from the vicinity of Crugers. The mica schist shows a constantly increasing metamorphism as the intrusive rocks are approached. Garnet becomes very abundant, and other contact metamorphic minerals such as sillimanite, cyanite and staurolite make their appearance.

The inclusions of schist in the igneous rocks themselves naturally also show the effects of contact metamorphism. G. S. Rogers[38] has come to the conclusion that the emery deposits which appear at several localities in the Cortlandt series are due to the more or less complete absorption of such inclusions by the intrusive magma before it solidified.

Croton Falls Hornblendite

A similar but smaller area of basic intrusives having very much less variation in composition occurs in the vicinity of Croton Falls. This mass is about two and a half miles long and one-half mile wide starting in at a point a little south of Croton Falls and extending in the form of a ridge in a northeasterly direction on the east side of the Croton River.

The rock at the northeastern end of this area is a massive dark green coarsely crystalline hornblendite. Some biotite is also visible in the hand specimen along with the hornblende. In thin section, under the microscope, it shows a coarse granitoid texture. In mineral composition,

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[36] G. S. Rogers: *Op. cit.*, pp. 54-55.
[37] Am. Jour. Sci., 3rd ser., Vol. XXXVI, pp. 254-269. 1888.
[38] *Op. cit.*, p. 81.

it consists principally of a dark green hornblende and minor amounts of dark brown biotite. Titanite, magnetite and a little pyrite appear as accessory minerals. The hornblende shows marked pleochroism from yellowish brown through greenish brown to deep green. The biotite also exhibits intense pleochroism from light yellowish brown to deep brown. This biotite hornblendite represents the typical composition of the intrusive mass at the northeast end of the area.

Along the eastern margin, the contact of the hornblendite with the mica schist may be observed at several places. At one point several apophyses of hornblendite were noticed extending into the schist. Some of these retain the coarse crystalline texture of the main mass, while others are somewhat finer grained. A thin section of this finer grained type under the microscope shows medium granitoid texture and massive structure. It consists almost entirely of hornblende with marked pleochroism from light yellowish brown through greenish brown to dark brownish green. It has well developed prismatic cleavage. A little plagioclase and titanite are present as accessory constituents.

A short distance to the east of this occurrence, several sheets of hornblende schist similar to those already described occur interstratified with the mica schist. This rock shows a distinct foliated structure. When examined under the microscope, it is seen to consist largely of a deep green hornblende, feldspar and a little quartz. The accessory minerals are magnetite, biotite and apatite. The hornblende shows marked pleochroism from light yellowish brown through greenish brown to deep green and has well developed prismatic cleavage. It does not show good crystal boundaries but occurs in irregular grains interlocked with the feldspar and quartz. These grains are usually oriented parallel to the foliation. The feldspar is chiefly plagioclase giving extinction angles up to 26° in sections at right angles to the albite lamellæ and is evidently an acid labradorite. Unstriated feldspar also is present. The feldspar grains are irregular in shape and usually elongated parallel to the foliation, but they do not show any crystallographic orientation. It is quite evident that this rock has had a different history from that of the apophyses of hornblendite occurring in the schist. The former was intruded prior to the period of folding, while the latter either at the close or else after it had ceased entirely.

At the southwestern end of the area, the hornblendite in places grades into a diorite. A section of the typical hornblendite as developed here was made from a specimen taken from the east side of the railroad at about one-quarter of a mile south of Croton Falls. It is a massive dark green biotite hornblendite. In thin section, it shows a coarse granitoid texture. The principal mineral present is a dark green hornblende associated with minor amounts of dark brown biotite. Small amounts of feldspar, both striated and unstriated, and a very little quartz occur in addition to the above, together with such accessory minerals as magnetite, apatite and titanite. Some of the hornblende is full of little quartz inclusions. Considerable evidence of strain is present in the section in the form of undulatory extinctions and wedge-shaped twins in the feldspar.

On the west side of the track in the same cut, the rock has taken on the composition of a diorite. The feldspar and hornblende appear in about equal amounts. Most of the rock is massive, but some of it shows a slightly foliated structure. In thin section, the texture is granitoid. The principal minerals present are a feldspar, a deep green hornblende and a dark brown biotite, together with minor amounts of magnetite, apatite and titanite. The feldspar is mostly plagioclase, giving extinction angles up to 22° 30′ in sections at right angles to the albite lamellæ, which would indicate andesine. Some orthoclase also is present, as much of the feldspar is unstriated and optically negative.

A number of inclusions of a schistose rock occur in the diorite at this place. Their contacts with the latter are usually quite sharp. A thin section of one of these, which forms a tabular, nearly vertical mass about four feet wide, shows a marked foliated structure and medium-grained crystalline texture. The principal minerals present are biotite, hornblende, feldspar and a little colorless pyroxene. Magnetite, apatite and titanite are accessory constituents. The hornblende is a deep green variety showing marked pleochroism from yellowish brown through brownish-green to deep green. The biotite shows intense pleochroism from light yellowish brown to deep brown. The feldspar is mostly plagioclase, giving extinction angles up to 20° 30′ in sections at right angles to the albite lamellæ, and is evidently an andesine. Another section from a somewhat similar inclusion also shows a marked foliated structure. A dark green hornblende is the principal mineral, associated with which are deep brown biotite and minor amounts of apatite, titanite and pyrite.

In the railroad cut at Croton Falls itself, a dark nearly black foliated rock is exposed. It has a medium coarsely crystalline texture. The thin section reveals a deep green hornblende with well developed prismatic cleavage, deep brown biotite and plagioclase. The accessory minerals are magnetite and titanite. Farther north in the same outcrop, the structure becomes even more foliated. A thin section from a specimen taken near the northern end of the cut shows a marked schistose structure. The minerals making up the rock are deep green hornblende with well developed prismatic cleavage, deep brown biotite, pale green augite and feldspar. The feldspar is mostly plagioclase, an andesine, with extinction angles up to 22° in sections at right angles to the albite lamellæ. It is optically positive. Feldspar is occasionally contained in the augite as inclusions. Titanite, apatite and magnetite occur as accessory constituents.

This area of foliated diorite gneiss apparently represents an intrusion of rather basic igneous rock which entered prior to or else during the early stages of the period of folding which involved the whole region. The hornblendite, on the other hand, was intruded during the latter stages or else after folding had ceased entirely. There are, therefore, two periods of igneous intrusion of rocks very similar in composition represented. The inclusions of diorite gneiss in the diorite itself south of Croton Falls are in accord with such a hypothesis. The hornblendite intrusions at Croton Falls were probably contemporaneous with that of the Cortlandt series at Peekskill. The hornblendite is in turn cut by a number of large dikes of granitic composition, sometimes reaching a thickness of two hundred feet or more. These range from true granite to coarse pegmatites, a variation of texture which often appears in the same dike within a very short distance. A discussion of these granitic intrusives will be taken up later. Reference is made to them here to show that the entrance of the hornblendite took place prior to the granite.

Diorite Dikes in the Vicinity of Bedford

Two occurrences of diorite in the form of dike-like intrusions have been described by Professors Luquer and Ries from the vicinity of Bedford in their paper on the geology of this region.[39] One of these occurs along the Bedford-Long Ridge Road about two and one-half miles southeast of Bedford. The rock has a dark color, medium, coarsely crystalline texture and massive structure. In thin section, one observes deep green hornblende, showing good prismatic cleavage, pale green augite and feldspar. Most of the feldspar is unstriated but is optically positive and therefore plagioclase. Titanite and apatite occur as accessory constituents. The augite apparently crystallized out before the hornblende, but the two are very intimately intergrown. Both minerals are perfectly fresh. Some of the feldspar has undergone slight alteration to an aggregate of quartz, sericite and calcite.

A similar rock occurs about two and one-quarter miles south of Bedford. It also has a dark green color, medium coarsely crystalline texture and massive structure. A thin section reveals light green hornblende

[39] Am. Geol., Vol. XVIII, pp. 239-261. 1896.

with good prismatic cleavage, dark reddish brown biotite and feldspar. The feldspar is mostly plagioclase, giving extinction angles up to 16° 30′ in sections at right angles to the albite lamellæ. It is probably andesine. A little microcline is also present. Much of the feldspar has been altered to an aggregate of kaolin, sericite and quartz. Inclusions of biotite occur both in the feldspar and amphibole, especially in the former. Apatite, magnetite and a little titanite are present as accessory constituents. A little pyrite forms an introduced mineral. In the edge of the mass, the rock becomes very much finer grained. In thin section, however, one still finds the granitoid texture. About equal amounts of light green hornblende and dark brown mica are present. The other important constituent is a plagioclase feldspar, evidently andesine, as it gives extinction angles up to 20° 15′ in sections at right angles to the albite lamellæ. Some orthoclase also occurs, together with minor amounts of apatite, titanite and magnetite.

Several other occurrences of diorite were observed in the area south of Bedford. Sheets of hornblende schist are also quite numerous in this vicinity, and the evidence again indicates that the intrusion of basic igneous rocks took place at more than one period.

Serpentine

Serpentine is associated with the Manhattan schist at several places in the area under discussion. These areas of serpentine are very similar to the massive basic intrusive rocks just described, both in their mode of occurrence and in their relations to the mica schist. D. H. Newland,[40] who has made a rather detailed study of them, has shown that they were derived from basic intrusives, probably peridotites, which have undergone serpentinization.

The largest of these serpentine masses underlies the northern portion of Staten Island. Smaller areas occur at Hoboken, New Rochelle and Rye. Newland, in his study of the Staten Island serpentine, came across unaltered remnants of olivine in some of his sections, showing that the serpentine was derived from an olivine-bearing rock. The writer has also noticed similar remnants of olivine in several sections from this locality. A thin section of the dark green massive serpentine from near the northern end of the area at Rye was also examined under the microscope. It consists of antigorite, bastite, some calcite, iron oxides, a very little tremolite and a few remnants of unaltered olivine, with a green spinel or pleonaste and magnetite as minor accessories. The bastite was

[40] School of Mines Quart., Vol. XXII, pp. 307-317 and pp. 399-410. 1901.

apparently derived from a pyroxene, while the antigorite represents altered olivine, as it shows the typical mesh structure and occasionally contains cores of unaltered olivine. Some of the serpentine from the same locality has a slightly banded structure. A thin section of this phase shows a distinctly foliated structure under the microscope and consists largely of tremolite oriented parallel to the foliation, with antigorite filling in the space between its prisms as well as the little crevices and cracks throughout the section. The tremolite is perfectly fresh and shows no alteration to serpentine. Some calcite is also present in the section. The accessory minerals are fairly abundant pleonaste and magnetite.

As has already been pointed out, these serpentine masses undoubtedly represent altered basic intrusive rocks rich in olivine. From their massive structure, it would appear that they entered either toward the close of the period of folding or after it had come to an end. They are, therefore, probably closely related to the Cortlandt series, the Croton Falls hornblendite and the Bedford diorite which have already been discussed.

Views with regard to the alteration of peridotites and allied olivine rocks to serpentine have changed considerably in recent years. It was formerly thought that the alteration was brought about by the processes of weathering, but now it is quite generally believed to be deep-seated.[41] Heated waters probably following closely upon the intrusion of the magma itself and given off by it during solidification, it is thought, have brought about the alteration of the olivine to serpentine while still buried at considerable depths.

Hornblende Porphyrite

A dike of hornblende porphyrite crosses the granites and pegmatites in a large cut just north of Springdale, about four and one-half miles out of Stamford on the New Canaan branch of the New York, New Haven and Hartford Railroad. As this is the only occurrence of a basic intrusive which is clearly of later age than the granitic intrusives in the area studied, a brief description of it will not be out of place.

The dike is about three and one-half feet thick at its widest part but is quite variable. The strike of the dike is about N. 48° E., and the dip is practically vertical. In a hand specimen, it shows a felsitic texture and dark green color. When examined in thin section under the microscope, the texture is apparently ophitic, but the space between the feldspar laths is occupied by hornblende instead of augite. The rock con-

[41] Ernst Weinschenk: Allgemeine Gesteins-kunde als Grundlage der Geologie, pp. 119-121. 1902.

sists essentially of plagioclase feldspar and hornblende, with magnetite, apatite and a very little biotite as accessory constituents. The plagioclase gives extinction angles up to 28° in sections at right angles to the albite lamellæ and is apparently an acid labradorite. The hornblende is a green variety occasionally showing typical prismatic cleavage. It occurs in small grains between the feldspar laths, and these are frequently encroached upon by it so that the crystallographic boundaries of the feldspar are not clean-cut. This would suggest that the space between the latter might originally have been occupied by augite which had afterwards altered to hornblende. No traces, however, of augite were noticed in the section, and the hornblende in all other respects has the appearance of being primary.

ACIDIC INTRUSIVES

In addition to the basic intrusives already discussed, there are other types which are of granitic composition varying from true granites to very coarse pegmatites and occurring as dikes, intrusive sheets and lenticular masses injected parallel to the foliation of the schist. The sheets and lenticular masses are far more abundant than the dikes. They appear in one form or another in nearly every outcrop of mica schist. Large masses of granite in bosses and batholiths outcrop, especially in Connecticut just beyond the New York line, where they become quite abundant. The Connecticut Geological Survey has given them the name Thomaston[42] granite.

Thomaston Granite

As typically developed, the Thomaston is a light colored biotite granite of medium to fine grain. It consists essentially of feldspar, quartz, biotite and muscovite. At many places, it shows practically no gneissic structure, but at other places is quite strongly foliated.

The granite covers a large area in the vicinity of New Canaan. It is well exposed in a railroad cut about one-half mile south of New Canaan on the New Canaan branch of the New York, New Haven and Hartford Railroad. It is a light pink massive granite with medium-grained texture. When examined in thin section under the microscope, it shows a granitoid texture and consists of microcline and a little plagioclase. A perthitic intergrowth of orthoclase and plagioclase may be occasionally noticed. Apatite and zircon are present as accessory constituents. Some of the feldspar has undergone slight alteration to kaolin and sericite, while a little chlorite is developed on some of the biotite.

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[42] Preliminary geological map of Connecticut. Conn. Geol. and Nat. Hist. Surv. Bull. No. 7. 1907.

Farther south along the same railroad, just north of Springdale, another large cut has been made in this same granite. The granite has a coarse pegmatitic texture in places, although much of it remains normal, medium-grained granitoid. The gradation from one into the other is a gradual one. It contains several inclusions of a basic igneous rock. These are usually massive and have a coarse crystalline texture and dark green color. A thin section made from one of them shows a granitoid texture and consists of green hornblende with good prismatic cleavage and deep brown biotite. A little titanite is present as an accessory constituent. The space formerly occupied by feldspar is now filled with an aggregate of calcite, quartz and other secondary products.

The gneissoid phase of the Thomaston granite is well shown in the vicinity of the Stamford reservoir, south of North Stamford. The locality is near the western border of the New Canaan mass and inclusions of schist are a prominent feature. It is to these that the banded structure of the gneiss is partially due.

Several smaller bosses of a similar granite occur to the west. One of the largest is just west of Pelhamville in the vicinity of Mount Vernon. The rock has a light gray color with a distinctly gneissoid structure and medium-grained crystalline texture. Under the microscope in thin section, it is granitoid and consists of microcline, quartz, orthoclase, some biotite and muscovite and a little plagioclase. Apatite is the principal accessory constituent.

Aplites and Pegmatites

Closely related genetically to the granites just described are a large number of intrusive sheets and dikes varying in texture from medium granitoid to very coarsely pegmatitic. Of these the intrusive sheets and lenticular masses injected parallel to the foliation of the mica schist are the most abundant. They appear in nearly every outcrop of the schist. Sometimes the injections are so numerous that the schist takes on a gneissoid appearance and becomes an injected gneiss (Pl. X, Fig. 1). They vary greatly in size from sheets 50 feet or more in thickness to those less than an inch thick. The same is true of the lenticular masses. The intrusives which are parallel to the foliation of the mica schist are often involved in all the intricate folds which have been developed in the latter.

The dikes of granite and pegmatite, on the other hand, cut across the foliation. They also cut the intrusive sheets and lenses and likewise each other, showing that they did not all enter at one time but that some are later than others. They also vary greatly in size. In some cases, as at Bedford Village, they reach a width of over two hundred feet, while in other cases they only have a thickness of a fraction of an inch.

In mineral composition, they vary from true granites and aplites in the case of the medium-grained varieties to nearly pure quartz veins in the case of the pegmatitic types. In the pegmatites, the greatest variation in mineral composition is found. They range from coarse-grained granite to pure quartz. In addition to the orthoclase, plagioclase (either albite or oligoclase), quartz, muscovite, biotite and black tourmaline which are most frequently present, a great many other more unusual minerals are sometimes available for the collector. Among these, the following have been identified by various mineralogists: amphibole, apatite, antunite, beryl, chrysoberyl, columbite, cyanite, cyrtolite, dumortierite, garnet, ilmenite, iolite, monazite, pinite, titanite, uraconite, uraninite, uranotile, xenotime and zircon.

In texture, these pegmatites are often very coarse. Feldspar crystals may reach a length of several feet, as in the case of the Bedford dikes, and many of the other accompanying minerals will have a correspondingly large size.

Some interesting structural features are also developed in the pegmatites at times. Very coarse pegmatite may often be associated with medium-grained granite in the same dike or sheet. The gradation from the one into the other may be a gradual one or it may be quite abrupt. Where such relations occur between granite and pegmatite, the former appears to have been intruded first and to have been followed closely by the latter, sometimes before the first had had an opportunity to completely solidify. Often the granitic phases in the case of the intrusive sheets show an original gneissoid structure.

A banded structure very similar to that sometimes seen in true veins is also developed (Pl. IX, Fig. 2). In instances, this structure is due to the growing inward from the walls of crystals of some of the minerals present, very often the muscovite. At other times, it is due to the progressive increase in size of the crystals of the mineral constituents from the walls inward. It may also be brought about when the intrusion of a granite or aplite is closely followed by the injection of pegmatite along the same fissure and before the former has had an opportunity to cool and completely solidify.

In the above description, it has been assumed that the pegmatites are of igneous origin, a view now quite generally accepted by geologists.[43] It is thought that they represent the final products of crystallization of rock magmas. They are the "mother liquor" so to speak, containing the bulk

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[43] W. C. Brögger: Syenit Pegmatitgänge der süd norwegischen Augit und Nephelinsyenite. Zeits. f. Kryst. u. Miner., Vol. 16, pp. 215-235. 1890.

Joseph P. Iddings: Igneous Rocks. Vol. I, pp. 273-276. 1909.

Alfred Harker: The Natural History of Igneous Rocks, pp. 293-299. 1909.

of the water, boric, carbonic and hydrosulphuric acids, the fluorides, chlorides and borates of the alkali metals and of the rare earths along with some of the silicates, free silica and other oxides which remain behind after the greater portion of the magma itself has solidified. This "mother liquor" is later extruded through fissures developed in the cooling mass and the pegmatites are, therefore, found as dikes in the igneous rock from which they were derived and in the adjacent wall-rock.

The exceedingly coarse crystalline texture and accompanying structures of the pegmatites are due to the presence of the gases and mineralizers in the magma from which they crystallized. Just what per cent of the entire amount of the residual magma they represent is hard to say. Professor Iddings[44] states that the proportion of gas present probably does not amount to more than ten times that present in the original magma from which the pegmatitic "mother liquor" was differentiated. From this it varies greatly down to cases where it is the same as the parent magma. A medium-grained granite or aplite then results.

The pegmatites of southeastern New York State are undoubtedly related genetically to large batholithic masses of intrusive granite. It is highly probable that the large areas of granite previously described which have been so extensively uncovered by erosion in western Connecticut represent these intrusive masses. The area farther to the west is very likely also underlain by other batholiths which have not yet been exposed except in an occasional projecting knob. Where the granite appears at the surface in western Connecticut, it often passes, as already mentioned, into coarse pegmatite. The transitions can best be explained by imagining the pegmatites to be injected into overlying but only partially cooled and solidified portions of the original magma. The two would then be very closely related. Also as these granite areas of western Connecticut are approached, the pegmatitic sheets and dikes become very abundant and of extensive size, indicating that there must be some common genetic relation between them.

The granitic intrusions just described probably accompanied the great orogenic movements which resulted in the intense folding of the rocks of this region, including the Inwood limestone and Manhattan schist. Such periods, as Professor C. R. Van Hise[45] has pointed out, are very favorable for the entrance of igneous rocks. The relations of the intrusive sheets and injected lenses of pegmatite and granite to the mica schist are such that they must in many cases have penetrated the older rocks before the period of folding had come to an end. The sheets and lenses are often as

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[44] *Op. cit.*, p. 276.

[45] "Earth Movements." Trans. Wis. Acad. Sci. Arts and Letters, Vol. II. 1898.

intricately folded as is the schist itself. On the other hand, they do not show much evidence of having come in prior to the folding since; had that been the case, evidences of considerable crushing and recrystallization of the coarse pegmatite would be expected. The crushing and recrystallization, however, fail, as the texture of the sheets and lenses is practically the same as that of the dikes which were intruded later and which are not involved in the folds. It seems reasonable, therefore, to believe that the first intrusions of granite and pegmatite accompanied the period of folding itself.

In the case of the Manhattan schist, the shales which were converted into mica schist during this period of folding yielded most readily along planes parallel to the bedding and naturally the early intrusions followed these lines of weakness, giving rise to the intrusive sheets and injected lenses which were drawn out and pinched off during the folding. In the case of the Inwood limestone, conditions were somewhat different. This was a more massive formation, and the bedding planes were not particular lines of weakness. Very few intrusives entered parallel to them. The magma rose through fissures and gave rise to true dikes where it solidified. These dikes are usually of fairly large size when they do occur, but they are not as abundant as in the mica schist (Pl. IX, Fig. 1).

The intrusive activity continued during a long interval of time, extending even beyond the period of folding. The later intrusions took the form of dikes which often cut one another, showing that some came in earlier than others, thus emphasizing the fact that igneous manifestations continued for a long time after the folding had ceased. The relations are not surprising because the pegmatites represent the final differentiation products of the great masses of granite.

In the case of igneous intrusions so richly supplied with water and other mineralizers as the pegmatites must have been, rather marked contact metamorphic effects would naturally be expected, especially in the case of the limestones. In their field occurrence, however, this does not appear to be the case. The dikes of pegmatite ten feet or more thick, apparently have produced no contact metamorphic effects on the limestone whatever. The explanation for this may be the one which Dr. E. Weinschenk[46] has given, namely, that when the pressure at the time of the intrusion is sufficiently great the CO_2 of the calcite and dolomite does not have an opportunity to escape, and hence the silica cannot combine with the lime and magnesia to form silicates. Occasionally the schist in immediate contact with the pegmatite becomes very rich in garnet. These contact phases of

[46] Grundzüge der Gesteinskunde, I Teil, p. 105. 1902.

the schist usually have also a very high content of feldspar, a portion of which was undoubtedly derived from the pegmatite. Cyanite occasionally appears, in long bladed crystals having a slight bluish tinge, in portions of the schist which have been thoroughly saturated with pegmatitic material. In this case, it is apparently of contact metamorphic origin. Undoubtedly the pegmatites derived a portion of their constituents from the rocks through which they were intruded. Such minerals as garnet and biotite probably owe their origin to this source. Black tourmaline similar in every respect to that found in the pegmatite itself often occurs in the mica schist in the vicinity of the pegmatitic intrusions and has evdently resulted from the emanations from this source.

That these granitic and pegmatitic intrusions played a very important role in the metamorphism and recrystallization of the original shale of the Manhattan formation into mica schist, there can be but little doubt. Most of the water associated with the intrusions must have been given off when solidification occurred, since it does not enter into the composition of any of the resulting minerals to any extent. This water must have been very effective in bringing about recrystallization. The local temperature must also have been raised by these intrusions. Edson S. Bastin[47] in his study of the Maine pegmatites has come to the conclusion that they crystallize at a temperature in the neighborhood of 575° C. The New York pegmatites are very similar to the Maine occurrences. These intrusions must, therefore, be regarded as very effective agents in the metamorphism of the original shale into mica schist. Other influences were the deep burial beneath overlying sediments and the severe folding and crumpling which followed the deposition of the original sediments.

Bedford "Augen" Gneiss

In discussing the mica schist in the vicinity of Bedford Village, mention has already been made of the "augen" gneiss which is so frequently associated with it. The region in which the structure occurs covers an ovoid area southeast of Bedford Village. The long axis extends in a northeast-southwest direction and has a length of about six miles. The width does not exceed two and one-half miles.

The "augen" structure is developed in two types of rock, a mica schist and a hornblende schist, but the entire area does not have the "augen" structure. It appears in bands usually parallel to the foliation. The bands grade into the ordinary schist by the gradual disappearance of the "augen" (Pl. X, Fig. 2). Sometimes the "augen" stop rather suddenly,

[47] U. S. Geol. Surv. Bull. No. 445, p. 45. 1911.

while at other times they drop out very gradually, so that the gradation from schist into "augen" gneiss is an almost imperceptible one. The width of these belts varies from those less than a foot to those several hundred feet wide.

About two-thirds of a mile southeast of Bedford Village along the road to Stamford, the "augen" gneiss is associated with a mica schist. In thin section under the microscope, the schist shows a moderately fine crystalline texture and a distinctly foliated structure. It consists chiefly of quartz, biotite and feldspar. The biotite is a deep reddish brown and is oriented parallel to the foliation. The feldspar is mostly plagioclase which gives extinction angles up to 30° in sections at right angles to the albite lamellæ. It is optically positive and is evidently an acid labradorite. Some microline is also present. The quartz and feldspar occur in irregular interlocking grains sometimes elongated parallel to the foliation. Pyrite and a little apatite are also present.

The "augen" of the gneiss consist of a pink feldspar twinned on the Carlsbad law and reaching a length of over an inch. They are very often rectangular in outline, although the ends are usually rounded. At other times, they take on an elliptical shape. The long axes are usually oriented parallel to the foliation, although not always so. "Augen" of white feldspar showing albite twinning are also present, but they do not reach as large a size as the pink ones. These give extinction angles up to 13° in sections at right angles to the albite lamellæ and are probably albite. Beside the feldspar, fairly large grains of quartz sometimes appear in veinlets with finer feldspar. In thin section, the pink feldspar is seen to be mostly microline. At times it exhibits a perthitic intergrowth with plagioclase. Quartz is seen in little veinlets throughout the rock. It sometimes contains inclusions of rutile. The finer matrix of the "augen" gneiss is very similar to the mica schist already described. It consists of quartz, a deep brown biotite, feldspar, mostly microline, and a little magnetite. The structure is distinctly foliated. The "augen" gradually disappear at the outer margins of the belt of "augen" gneiss which grades into the schist. Where typically developed the "augen" constitute a large percentage of the entire mass of the rock.

Another specimen of the "augen" gneiss taken from a belt along a road about one mile south of Bedford shows only a pink feldspar which is nearly always twinned according to the Carlsbad law. The feldspar is not as abundant as in the occurrence described above but is similar in size, shape and orientation (Pl. XI, Fig. 1). Small veinlets of pegmatitic material parallel to the foliation are present. "Augen" of feldspar are occasionally associated with these. In thin section, the matrix in which the feldspar "augen" are imbedded has a medium-grained crystalline texture and distinctly foliated structure. Its minerals are quartz, biotite, some feldspar, mostly microcline, and a little plagioclase. Apatite occurs as an accessory constituent. Many little veinlets of introduced quartz parallel to the foliation are present with which the feldspar "augen" are sometimes associated. These feldspar "augen" consist of orthoclase and microcline and sometimes show a perthitic intergrowth with plagioclase.

About two miles south of Bedford along an east and west road, there is an interesting outcrop which exhibits a transition from a true pegmatitic sheet parallel to the foliation, into "augen" gneiss and finally into mica schist with only a few "augen" of feldspar. Plate XI, Fig. 2, shows a specimen in which prominent "augen" of pink feldspar are developed along little pegmatitic stringers with which the schist is thoroughly injected.

About one and one-half miles northeast of North Castle, the "augen" structure is developed in a hornblende schist. This is a black more or less foliated rock. In thin section, one observes plagioclase, dark green hornblende with good prismatic cleavage and deep brown biotite. The plagioclase gives extinction angles up to 12° in sections at right angles to the albite lamellæ and is therefore oligoclase-andesine. Apatite is an abundant accessory constituent. Magnetite and a little titanite are also present. The "augen" show very much the same characteristics as those already described. They consist of orthoclase and some microcline. In one case, a micrographic intergrowth of orthoclase and quartz was noticed. The bands of "augen" gneiss here have very much the same relation to the hornblende schist as the others did to the mica schist. In this case, the matrix in which the "augen" occur consists essentially of the same constituents as the hornblende schist.

Professors Luquer and Ries,[48] in their study of this "augen" gneiss, came to the conclusion that it represents a metamorphosed igneous rock of the composition of a granite or aplite. The metamorphic action, they thought, produced the gneissoid structure by pressure and a granulation of the minerals, the unsheared portions of the rock remaining as "augen."

A chemical analysis made by the writer of the "augen" gneiss described from the outcrop along the road two-thirds of a mile southeast of Bedford Village along the road to Stamford gave the following composition:

[48] *Op. cit.*, p. 205.

Analysis of Augen Gneiss

	Per cent
SiO_2	67.02
Al_2O_3	13.96
Fe_2O_3	2.36
FeO	2.73
MgO	1.27
CaO	2.69
Na_2O	3.61
K_2O	5.27
H_2O +	.36
H_2O —	.02
TiO_2	1.41
Total	100.70

Norm

	Per cent
Quartz	19.08
Orthoclase	31.69
Albite	30.39
Anorthite	6.12
Diopside	5.74
Hypersthene	1.26
Magnetite	3.48
Ilmenite	2.62
Total	100.38

Magmatic symbol II. 4.23. Adamellose.

The analysis would rather seem to uphold the above conclusions as it corresponds to that of an igneous rock of about the composition of a quartz monzonite.

There are other features, however, which cannot very well be explained by such a hypothesis. The occurrence of the "augen" gneiss in bands of varying width and their gradation into mica schist or hornblende schist cannot very well be explained by such a supposition. The fact that where the "augen" gneiss is associated with mica schist, its matrix has the composition of the mica schist and where, with hornblende schist, that of the hornblende schist, does not favor such a conclusion. If the "augen" gneiss represents a metamorphosed igneous rock in which the feldspar "augen" represent original unsheared feldspar crystals, the original rock must have had a very coarse granitoid texture or else a porphyritic texture in which the phenocrysts were feldspar. In either case, it is hard to see why these "augen" of feldspar should have their present distribution in local belts through the rest of the rock. It is also hard to account for such a variation in matrix as is represented in different places.

The apparent gradation of a pegmatite sheet into "augen" gneiss by a thorough injection of the adjoining schist with pegmatitic material, and the final gradation of this into true schist with only a few "augen" of feldspar, suggests that the "augen" gneiss represents sheared zones of schist which have been thoroughly injected and permeated with pegmatitic material consisting largely of potash feldspar together with some plagioclase and quartz. The only peculiar feature, assuming that this is the correct explanation, is that the feldspar took on a more or less crystalline outline. That this injection belonged to the earlier stages of the pegmatitic intrusions is shown by its relationship to the other schist and the later pegmatitic intrusions.

The frequent association of these feldspar "augen" with little veinlets of secondary quartz and pegmatite favors such a hypothesis. The fact that micrographic and perthitic intergrowth are occasionally present in the orthoclase and microcline also points toward such an origin as such intergrowth would hardly be expected in feldspar representing phenocrysts of a sheared porphyry. The variation in the mineral composition of the matrix can also be explained on this basis, as it would be that of the sheared rock into which the injection took place.

Occurrence of Zeolites in the Manhattan Schist

Zeolites are occasionally found lining cavities and small crevices in the Manhattan schist. Among them, thomsonite, natrolite, analcite, chabazite, phacolite, harmatome, heulandite and stilbite have been reported from Manhattan Island.[49]

Specimens of stilbite and chabazite occurring in the Manhattan schist in this manner were given to the writer by Mr. J. R. Healy, assistant engineer with the New York Board of Water Supply. They were obtained from Shaft 15 of the Catskill aqueduct at 65th Street and Central Park West. The crystals of stilbite and chabazite lined the walls of a small open crevice which followed the plane of schistosity of the mica schist for a short distance. The stilbite has a honey-yellow color and has crystallized in sheaf-like and radiated masses. The chabazite is white in color and has a nearly cubic form. It precedes the stilbite in order of crystallization, as the latter sometimes grows on top of it. Little veinlets of pegmatitic material and epidote occur in the schist closely associated with the stilbite and chabazite.

When examined in thin section under the microscope, it is seen that much of the biotite of the mica schist has been altered to chlorite. The orthoclase of the little pegmatite stringers is also much kaolinized. Associated with these pegmatitic stringers but later in origin are veinlets of quartz, which, under the microscope, appear as a fine mosaic of little grains. Veinlets of epidote with a little accompanying calcite are often associated with these quartz stringers and cut them in such a way as to show that they were the last to be introduced.

The formation of the zeolites probably accompanied the last stages of the pegmatitic intrusions. The zeolites were probably deposited by

[49] B. B. Chamberlin: "The Minerals of New York County." Trans. N. Y. Acad. Sci., Vol. VII, No. 7. 1888.

the accompanying heated waters in little crevices which had been developed after the period of folding had come to an end. In the modern view,[50] zeolites are believed to have been deposited by heated waters accompanying the last stages of igneous activity. The mere leaching of the necessary constituents by surface waters in the belt of weathering is not considered sufficient. Professor Brögger[51] has also described zeolites from pegmatite dikes where they occur as products of the last stages of crystallization.

Summary

The Manhattan schist is a series of much metamorphosed argillaceous and sandy shales, argillaceous sandstones and arkoses which represent a thickness of several thousand feet. The argillaceous sediments were laid down conformably upon the underlying limestone, the limestone grading into calcareous shales at the contact. After their deposition, they were penetrated by a series of basic igneous rocks, largely in the form of sheets and sills. Then a period of great orogenic movements set in which brought about intense folding in the whole area. The original sediments had been buried to a sufficient depth to come into the comparatively shallow zone of anamorphism for shales. A large series of granitic intrusions accompanied the folding. The granites are huge batholiths which have only been exposed by later erosion at the surface in a few places in this area. Radiating from the batholiths are numerous granitic and pegmatitic dikes. During the earlier stages, the intrusions occurred mainly along the bedding planes which were the lines of weakness, and in many places the rock was so thoroughly injected in this manner that it has become an injected gneiss.

The burial to a considerable depth and the intense stress set up by the orogenic movements which produced the folding, together with the metamorphic effects of the granitic and pegmatitic intrusions, brought about the recrystallization of the constituents of the original shale and associated sediments into mica and related schists. The earlier basic intrusives were also involved in the dynamic metamorphism. The metamorphism appears to be least pronounced north of Croton Village and in those places in the vicinity of Peekskill where the schist did not come under the influence of the local contact metamorphic effects of the Cortlandt series.

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[50] Waldemar Lindgren: "Some modes of deposition of copper ores in basic rocks." Econ. Geol., Vol. VI, pp. 687-694. 1911.

[51] Zeits. f. Kryst. u. Miner., 16 Band, pp. 168-173. 1890.

The granitic and pegmatitic intrusions, especially the latter, continued for some time after the folding had ceased. These later intrusions took the form of dikes. Toward the end of the period of folding, or perhaps after it had ceased altogether, a number of intrusions of basic igneous rocks occurred at several places in the area under discussion. The largest of these constitutes the Cortlandt series Near Peekskill. Some of the igneous rocks were rich in olivine and have been altered to serpentine. Granitic and pegmatitic intrusions were still occurring at the time, as these later basic rocks are cut by granite and pegmatite dikes in several places. A hornblende porphyrite cutting pegmatite near New Canaan, Connecticut, is the latest in age of the intrusives present in the region under discussion.

The age of the Manhattan schist, as already mentioned, is still a disputed question. This will be further discussed after the formations north of the Highlands have been described.

Peekskill Phyllite

As has already been mentioned in a previous chapter, the section across the Peekskill Creek valley northeast of Peekskill contains a series of formations which are quite different from those exposed anywhere else south of the Highlands, with the exception of Tompkins Cove on the west side of the Hudson River, which is merely a continuation of this same belt. The lowest member here resting upon the gneiss is a quartzite about six hundred feet thick. This is followed by a fine-grained crystalline limestone varying in color from blue to white which in turn is succeeded by a dark gray to black phyllite. On account of folding, it is hard to determine the exact thickness of the limestone and phyllite, but the former is probably about one thousand feet, while the thickness of the latter is probably a great deal more. The phyllite is well exposed on the northwest side of the valley which occupies the limestone belt, while the quartzite shows on the southeast side. All the formations dip steeply toward the southeast. Most of the phyllite has a dark bluish gray color and rather fine texture. Pyrite crystals are quite abundant in certain beds.

A thin section of the fine dark bluish gray rock, when examined under the microscope, shows a distinctly foliated structure and is found to consist largely of an aggregate of minute quartz grains and sericite flakes, with abundant iron oxides scattered through the whole mass and also to a certain extent concentrated in distinct bands parallel to the foliation. Occasionally, small stringers of secondary quartz also parallel to the foliation may be noticed.

A chemical analysis made by the writer of the above described specimens gave the following composition:

Analysis of Phyllite

	Per cent
SiO_2	61.04
Al_2O_3	15.87
Fe_2O_3	1.74
FeO	4.32
MgO	3.26
CaO	2.39
Na_2O	1.83
K_2O	3.26
$H_2O +$	1.82
$H_2O -$	.09
CO_2	4.24
TiO_2	.91
Total	100.77

A lighter colored coarser-grained type was also examined under the microscope. It consists largely of quartz and sericite, with minor amounts of black iron oxides. A little calcite in isolated crystals is also present. Recrystallization has proceeded much further than in the previous case. The sericite flakes are all oriented parallel to the foliation, while the quartz grains are all more or less elongated parallel to it (Pl. XIV, Fig. 1). An occasional quartz grain reaches a diameter of .5 millimeter, but most of them are much smaller.

All who have studied this section have correlated these formations with the Poughquag-Wappinger-Hudson River series north of the Highlands. Dr. Charles P. Berkey,[52] who has made the most recent and detailed study of this area, has come to the conclusion that these are not, however, the equivalent of the Inwood-Manhattan series south of the Highlands, as others have thought, basing his view upon the relation of the Peekskill Valley formation to a belt of limestone occupying Sprout Brook Valley to the northwest, which he thinks is the equivalent of the Inwood limestone. A further discussion of these two views will be taken up after the formations north of the Highlands have been described.

Poughquag-Wappinger-Hudson River Series

Just north of the Highlands of the Hudson and east of the Hudson River itself, a quartzite to which the name Poughquag has been given

[52] "Structural and Stratigraphic Features of the Basal Gneisses of the Highlands." N. Y. State Mus. Bull. 107, pp. 361-378. 1907.

rests unconformably upon the pre-Cambrian gneisses. This is followed conformably by a limestone known as the Wappinger, which in turn is succeeded by a thick series of shales belonging to the Hudson River group.

POUGHQUAG QUARTZITE

The Poughquag quartzite reaches a maximum thickness of about six hundred feet. It is usually a compact, granular silicified quartz sandstone of medium grain, with occasionally a fine conglomerate at the base and sometimes finer grained quartzitic shales at the top. Its fossil contents show that it is of Lower Cambrian age.[53]

In certain places, as along the Matteawan inliers of pre-Cambrian gneiss, a coarse granitic stratum rests on the upturned gneiss, and this is followed by a somewhat foliated, finer grained quartzitic rock. This granitic stratum has been interpreted by C. E. Gordon[54] as representing decayed portions of the old pre-Cambrian gneisses which were partly reworked by the advancing Cambrian sea and later covered by quartzitic sands.

Usually, wherever the relationship of the quartzite to the gneiss can be made out, the contact is seen to be an unconformity, and it is evident that the foliated structure of the gneisses dates back to a period of folding prior to the deposition of these Lower Cambrian sediments.

Since the deposition of the quartzite, the region has been involved in extensive thrust faulting which has shoved the older pre-Cambrian gneisses upon the later formations. In some cases, the quartzite moved with the gneiss, while in others the gneiss moved over it. The quartzite, although never violently folded, was nevertheless greatly disturbed by orogenic movements in certain places.

WAPPINGER LIMESTONE

Following the Poughquag quartzite just north of the Highlands comes the Wappinger limestone. In this region, it has a thickness of about one thousand feet. Portions of it are magnesian in character. A belt of this limestone runs from the Hudson River in a northeasterly direction along the northwestern margin of the Highlands and then turns northerly up the Clove Valley where it dies out. To the east of the Clove Valley, it passes underneath a thick series of phyllites and schists, appearing again farther east in the Dover-Pawling Valley.

C. E. Gordon[55] has identified fossils of Lower Cambrian, Beekmantown

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[53] J. D. DANA: Am. Jour. Sci., 3rd ser., Vol. 3, pp. 250-256. 1872.
[54] "Geology of the Poughkeepsie Quadrangle." N. Y. State Mus. Bull. 148, p. 46. 1911.
[55] *Ibid.*, p. 71.

and Trenton ages from this belt, showing that all these terranes are present. He called attention to the fact that as one goes eastward in this belt the rock displays greater crystallinity. Much evidence of crushing becomes manifest and bunches and veinlets of calcite, nests of quartz and stringers are abundant, indicating hydrothermal activity. These changes have obliterated all traces of organic remains.

The limestone of the Clove Valley is essentially a fine-grained gray to white crystalline variety. The individual calcite grains range in size from one-tenth to two-tenths millimeter in diameter. Small bunches and stringers of secondary quartz are frequently present. On the east and west, the limestone is overlain by phyllites belonging to the Hudson River series.

The limestone appears again six miles to the east in the Dover-Pawling Valley. Here it is considerably more metamorphosed, as is shown by its coarse crystalline texture. In places, as in the vicinity of South Dover and Wingdale, it is quite pure and makes an excellent marble. It has been quite extensively quarried at these places. At other localities, phlogopite and tremolite occur quite abundantly distributed through it. The development of tremolite crystals in the limestone is especially well shown in some of the cuts along the New England Railroad from Towners to West Patterson. They frequently become an inch long and over a quarter of an inch in diameter and make up a goodly percentage of the rock.

HUDSON RIVER SLATES, PHYLLITES AND SCHISTS

Resting on the Wappinger Limestone is a thick series of slates belonging to the Hudson River group. The slates range in age from Trenton into Cincinnatian.[56] These strata are strongly folded and crumpled, and for this reason their exact thickness is unknown, but probably exceeds several thousand feet.

Just east of the Hudson River, a slaty shale derived from an impure argillaceous mud is the predominating type. Interbedded with this shale are occasional sandstone beds. Following these slates eastward from the Hudson River, an increase in the amount of metamorphism which they have undergone becomes very noticeable. In the vicinity of Arthursburg, they have been altered to slaty phyllites and graywackes.

The formation at Arthursburg is typically a slaty phyllite broken up into a large number of comparatively thin lamellæ by numerous parallel cleavage planes. It has a dark bluish gray color and is fine grained. In thin section under the microscope, it is seen to be made up chiefly of a

[56] C. E. Gordon: N. Y. State Mus. Bull. 148, p. 96. 1911.

fine aggregate of quartz and sericite. The quartz occurs in minute grains usually more or less elongated parallel to the cleavage. The little sericite scales occur interspersed among the quartz with their basal section in the plane of cleavage. Considerable amounts of iron oxide occur scattered throughout the mass. A little biotite in minute scales has also commenced to develop. Bands with sericite predominating over the quartz alternate with bands in which the quartz predominate.

Going eastward, the rock begins to take on more and more the nature of a true phyllite. A thin section from a specimen obtained three miles east of Arthursburg has the grains of quartz and flakes of muscovite somewhat coarser than that at Arthursburg. Considerable chlorite also appears in this particular specimen. Oxides of iron are plentiful, often concentrated along more or less parallel bands. Magnetite occurs in grains up to five-tenths millimeter in diameter. In crystallizing, it has forced the other mineral aside, and the flakes of sericite now curve around it. The structure is distinctly foliated.

Four miles east of Arthursburg is a belt of Wappinger limestone, the more ready erosion of which accounts for the Clove Valley. On the east side of the valley, the phyllites are again found overlying the limestone. The rock has a rather fine texture, with numerous easily recognizable flakes of biotite scattered through it. Pyrite also is abundant. Under the microscope, the fine-grained mass is seen to consist of an aggregate of sericite and quartz, associated with which are large quantities of iron oxide in very fine particles. In the finer matrix occur numerous larger and more prominent flakes of biotite with their basal sections in the plane of foliation (Pl. XIV, Fig. 2). They all show a more or less ragged outline. Pyrite is present in considerable quantities. The fine-grained matrix in this case is a good deal more coarsely crystalline than that found west of the Clove Valley.

A short distance east of the above contact, the biotite becomes a very prominent feature. Occasional crystals of garnet also appear. Under the microscope, it is seen that the fine-grained mass of sericite, chlorite and quartz with some iron oxide is a little coarser than in the previous cases. This shows a distinct foliated structure. On the other hand, the biotite is not oriented parallel to the foliation but occurs in rather prominent flakes at all angles to it. A few isolated grains of garnet appear for the first time.

About one-half mile east of the above locality, the phyllite begins to grade into a fine-grained schist. The sericite or muscovite becomes quite abundant and gives the rock a satiny luster. Garnet becomes very prominent. Its crystals average about one-tenth inch in diameter and show good crystal outline. In thin section under the microscope, the rock shows a distinctly foliated structure and is seen to be made up of an aggregate of sericite and quartz. In it are large crystals of garnet, biotite and staurolite. The latter mineral makes its first appearance but is not as yet very abundant.

A specimen collected two and one-half miles east of the above locality shows abundant biotite and an occasional garnet crystal embedded in a fine-grained matrix. This matrix resolves itself under the microscope into an aggregate of quartz and sericite, with abundant iron oxide scattered through it. A little plagioclase and a few small tourmalines are also present. The rock shows a distinctly foliated structure (Pl. XIV, Fig. 3). It is evident that the metamorphic changes here have not reached quite so advanced a state as in the case above. Most but not all of the biotite crystals are oriented parallel to the foliation.

A specimen from an outcrop occurring three and one-half miles east of the Clove Valley showed a medium fine texture and distinctly foliated structure. Abundant garnet and biotite show in the hand specimen. Under the microscope, the main mass of the rock is seen to consist largely of quartz and sericite. The biotite is full of quartz inclusions.

A specimen collected a short distance east of the above locality shows a marked schistose structure. It has a silky luster due to the presence of numerous fine sericite flakes. Garnet and biotite are prominently developed. In thin section, the sericite flakes all show more or less parallel alignment to the foliation. Quartz occurs in small grains interspersed between the sericite. Biotite is present in considerable amounts in fairly large flakes embedded in this matrix. The same is true of garnet. An occasional staurolite crystal has also been developed. Some chlorite is present. The texture in this specimen is a good deal coarser than any described thus far.

A half mile east of this locality near the western contact of the Dover-Pawling limestone with the schists the rock is quite coarsely crystalline. Garnet, biotite and abundant staurolite crystals can be readily made out embedded in a fine matrix which has a silky luster due to the abundant presence of muscovite. The rock is a typical staurolite-mica schist. In thin section, the matrix is seen to be made up of medium-grained aggregate of muscovite and quartz, with an occasional grain of orthoclase and plagioclase (Pl. XIV, Fig. 4). The quartz occurs in fairly large grains at times. The flakes of muscovite are oriented parallel to the foliation. Biotite is also abundant and occurs in larger flakes than the muscovite also oriented parallel to the foliation. Staurolite and garnet with good crystalline outlines occur abundantly interspersed in this matrix. They are full of quartz inclusions. A little chlorite derived from altered biotite is also present.

After crossing the Dover-Pawling Valley, the schists are again exposed overlying the limestone on the east side of the valley. A specimen collected from the west slope of Purgatory Hill east of Pawling, when examined under the microscope, shows a medium coarse texture and distinctly foliated structure, due chiefly to the parallel orientation of the biotite (Pl. XIV, Fig. 5). The mineral composition is principally biotite, plagioclase, orthoclase and quartz. The plagioclase is present in large amount. It has a maximum extinction angle of 25°, measured in sections at right angles to the albite lamellæ, which would indicate an andesine or acid labradorite variety. A few small garnet grains and some magnetite are also present. The garnet is remarkably free from inclusions.

Another section examined from a specimen collected three and one-half miles east of Pawling shows a coarse-grained crystalline texture and schistose structure. It is composed mostly of biotite, feldspar, quartz and garnet. The biotite shows marked pleochroism from light yellowish brown to deep brown. Only minor amounts of muscovite are present. The feldspar consists mostly of plagioclase with some orthoclase. Considerable quartz is also present. A few small grains of staurolite and a single crytal of tourmaline were also noted in the section examined.

Going south along the contact of the Dover-Pawling limestone with the overlying schist, the schist does not vary a great deal in composition. In places, quartz becomes more prominent and the amount of feldspar increases.

On the north side of the valley at Haviland Hollow, east of Towners, a dense, dark, finely granitoid rock occurs apparently interbedded with the mica schists. It is being quarried for road metal. On examination in thin section under the microscope, the rock is seen to have a granitoid texture and to consist chiefly of the quartz, plagioclase and hornblende. The plagioclase gives extinction angles up to 32° 30′ in sections at right angles to the albite lamellæ. Some sections do not show the twinning but show good cleavage. They are biaxial and optically positive. The plagioclase is evidently labradorite. The hornblende shows marked pleochroism from brownish yellow through deep yellowish brown to dark green. A little biotite is present. Titanite occurs in considerable amount as accessory mineral. Magnetite and apatite are other accessory constituents which are present. The rock shows a cataclastic structure, and much of the quartz is undoubtedly of secondary origin. The mineral composition indicates an igneous rock of the composition of a quartz diorite. From the amount of dynamic metamorphism that it has undergone, it was evidently intruded into the shales now represented by the mica schist prior to the period of folding as an intrusive sheet.

Pegmatite sheets and dikes become quite abundant in the mica schists east of the Dover-Pawling Valley. These are usually present in the form of intrusive sheets and lenses, parallel to the foliation of the schists which in most cases also represents the bedding planes of this formation. Dikes also occur. West of the Dover-Pawling Valley, the pegmatites are not very prominent, occurring only occasionally in the schists just west of this valley. The tourmaline noticed in one of the sections of phyllite collected west of the Dover-Pawling Valley was probably derived from emanations given off by these pegmatitic intrusions.

HISTORICAL GEOLOGY

As seen from the above description of the formations north of the Highlands, a sandstone was laid down unconformably upon the upturned edges of the folded pre-Cambrian gneisses during lower Cambrian time. Then followed a period of limestone deposition which continued into Trenton time. Sedimentation was not continuous during this entire interval, but there were several retreats of the sea followed by re-advances, so that there are a number of breaks in the limestone represented by disconformities. These can only be recognized on paleontological evidence. The limestone deposition was followed by that of a thick series of dark shales which range in age from Trenton to Cincinnatian.

Then at the close of the Ordovician, there was inaugurated a period of great orogenic movement, commonly known as the Green Mountain uplift. The formations described were thrown into a series of anticlines and synclines whose axes have a northeast and southwest trend. Accompanying this folding, there occurred the intrusion of a large number of pegmatitic sheets and lenses in the eastern portion of the area, which are undoubtedly closely related to the granitic batholiths occurring still farther East in Connecticut. The quartz diorite described from Haviland Hollow, as already mentioned, was intruded prior to the folding.

The burial of these formations to a depth sufficient to bring them into the zone of anamorphism of Van Hise and the intense pressure accompanying the great orogenic movement which produced the folding together with the injection of a large amount of pegmatitic material had a marked metamorphic effect upon the formation involved, causing the limestone in the eastern portion of the area to become completely recrystallized and bringing about the formation of numerous lime and other silicates in it while the overlying shale was converted into a mica schist.

Going west from the Dover-Pawling Valley, the metamorphic effects become less and less noticeable, until in the vicinity of the Hudson River fossil remains can still be readily identified in the limestone, and the shale has hardly been converted into a slate. The transition from a garnetiferous staurolitic mica schist to a phyllite takes place within a distance of four and one-half miles in passing from the western margin of the Dover-Pawling Valley to the eastern side of the Clove Valley.

Such a change in so short a distance can hardly be explained on the basis of regional metamorphism alone. The axis of most severe orogenic disturbance runs in a northeast-southwest direction through western Connecticut and Massachusetts into Vermont. Here the pressure was greatest, as the folding and crumpling are much more pronounced than they are farther west where the beds become less disturbed. Along this line of most severe disturbance a series of granitic intrusions occurred at the time of the folding. These sent out radiating pegmatitic dikes and sheets into the adjacent formations which must have had a marked metamorphic effect upon them and have brought about the recrystallization of the constituents of the shale into mica schist as already pointed out in the case of the Manhattan schist.

Professor Van Hise[57] has described a very similar occurrence from the Black Hills of South Dakota where a great intrusive batholith of granite is surrounded by sedimentary rocks which are cut by a series of radiating pegmatitic dikes extending out from the central core. Remote from the intrusive, the sedimentary rocks are slates, while adjacent to them they are schists and gneisses.

From the study of the transition of slates to schists north of the Highlands, the following seems to be the order in which the different metamorphic minerals were developed. Sericite was the first new mineral to form and was accompanied by a partial recrystallization of the quartz present. The formation of chlorite may have occurred at the same time. Next biotite began to develop, the iron present in the form of oxide entering into its composition. Biotite was followed by garnet. Still later staurolite made its appearance. The sericite by this time had recrystallized into true muscovite. Feldspar also began to develop at this stage. As these changes were going on, the texture of the rock was growing progressively coarser. In the final stages, large quantities of feldspar appeared, while the muscovite became less abundant, the former developing at the expense of the latter. In some of these gneissic phases, the muscovite disappeared entirely. Staurolite also dropped out except for an occasional grain. The garnet become quite free from inclusions during these later recrystallizations.

[57] U. S. Geol. Surv. Mon. XLVII, p. 724. 1904.

Faulting has occurred in the region since the period of folding. In places along the northern borders of the Highlands, the pre-Cambrian gneisses have been thrust upon the paleozoic strata. This faulting probably accompanied the crustal movements which involved eastern North America at the close of the Paleozoic.

Comparison of Inwood-Manhattan and Poughquag-Wappinger-Hudson River Series

As has already been shown, there is still a marked difference of opinion as to the relationship of the Inwood-Manhattan series south of the Highlands to the Poughquag-Wappinger-Hudson River series to the north. One view is that they are equivalents, while the other is that the Inwood-Manhattan series consists of much older formations belonging to the pre-Cambrian. The arguments in favor of their being the same in age will be taken up first, and then those against such a correlation will be considered.

Probably the strongest argument in favor of the correlation of the two series is the fact that they represent almost the same lithological succession of formations, the only difference being that the one is more metamorphosed than the other. South of the Highlands, a quartzite is occasionally found overlying the gneiss, on top of which rests the Inwood limestone, followed by the Manhattan schist. Naturally, this quartzite has been correlated with the Poughquag quartzite north of the Highlands; the Inwood limestone has been regarded as the equivalent of the Wappinger, and the Manhattan schist has been considered the representative of the Hudson River slates by many geologists. The upper two formations in each case correspond quite closely in thickness, but the Poughquag quartzite on the other hand is usually much thicker than the Lowerre quartzite south of the Highlands, even where this is developed to its greatest extent.

From the descriptions of the Hudson River shale and slate and the Manhattan schist already given, it has been shown that the latter was derived from a sediment very similar in composition to that of the former, and where it has been sufficiently metamorphosed, as in the eastern portion of Dutchess County, it has been converted into a mica feldspar schist practically identical with the Manhattan schist. Likewise, the Wappinger limestone of the Dover-Pawling Valley in eastern Dutchess County also shows the same coarse crystalline texture that the Inwood limestone possesses and has tremolite and phlogopite developed in it to an equal extent.

A quartz diorite was found occurring at one place in the schist north of the Highlands which had practically the same relationship to the latter that the hornblende schist has to the Manhattan schist south of the Highlands.

The folding of the formations north of the Highlands was also accompanied in eastern Dutchess County and western Connecticut, where the folding was severest, by the intrusion of granites and pegmatites similar to those south of the Highlands. Those who hold that the two series are equivalent believe that the orogenic movements which brought about the folding and metamorphism south of the Highlands were also part of the Green Mountain uplift which occurred toward the close of Ordovician time and brought about the metamorphism north of the Highlands. The axes of the folds in the two regions run in the same general direction.

The occurrence of an area of phyllite south of the Highlands northeast of Peekskill has been cited as evidence in favor of the Ordovician age of the Manhattan schist, being regarded by those who hold to the Ordovician age of the schist as a less metamorphosed phase of this formation which is very similar to the Hudson River slates and phyllites north of the Highlands. This phyllite has been regarded by all who have studied it as of Ordovician age.

There is an interval of a little over one and a half miles between the nearest outcrops of phyllite and schist. As has already been remarked, where the schist southeast of Peekskill is at a sufficient distance from the contact metamorphic effects of the Cortlandt intrusive, it does not show as marked metamorphism as does the typical Manhattan schist farther south and southeast. Feldspar is almost entirely absent, and sericite is an abundant constituent of the rock. The schists north of Croton Village also are not as metamorphosed as the typical Manhattan schist of southeastern New York. Some of the garnetiferous staurolite mica schist very similar to that described from north of the Highlands is also present here. Clearly transition phases between phyllites and typical mica feldspar schist similar to those north of the Highlands are present in the area south of Peekskill and north of Croton Village, but in most cases they have been obscured by the contact metamorphism accompanying the intrusion of the Cortlandt series. As seen from the description of the schist north of the Highlands, the transition from phyllite to schist may take place within a comparatively short distance. It is reasonable to believe, therefore, that the Peekskill phyllite may represent a less metamorphosed phase of the Manhattan schist.

Of those who have made a careful study of the Manhattan schist, Dr. Charles P. Berkey[58] has given the best arguments against the correlation

[58] N. Y. State Mus. Bull. 107, pp. 361-378. 1907.

of this formation with the Hudson River series He bases his conclusions upon a number of facts.

One is the relation of the Peekskill Valley quartzite, limestone and phyllite to the crystalline limestone in the Sprout Brook valley. Dr. Berkey considers the former to represent a down-faulted block of the Poughquag-Wappinger-Hudson River strata, as already mentioned, while the latter, he thinks, is the equivalent of the Inwood, on account of its thickness and lithological resemblance to that limestnoe, and that it is not one of the interbedded limestones occurring in the pre-Cambrian Highland gneisses farther north. In the Peekskill Valley, there are five hundred feet of quartzite corresponding to the Poughquag quartzite, while in the Sprout Brook valley the limestone apparently rests upon the gneiss. This limestone, moreover, is very much more metamorphosed than that occurring in the Peekskill Valley. All these facts go to show that they cannot be correlated, and that if the former is the Inwood, the latter must be later in age.

Another strong argument against such a correlation is that a quartzite rarely appears between the Inwood limestone and the underlying Fordham gneiss, and where it does occur it is quite thin and can be followed for only a short distance. Where it is present, it appears to be a part of the gneiss, as it is conformable with it and apparently grades into it. At other places, the Inwood limestone rests conformably upon the Fordham gneiss. North of the Highlands, on the other hand, the Poughquag quartzite is usually well developed and reaches a thickness of six hundred feet in places. It rests unconformably upon the pre-Cambrian gneisses which Dr. Berkey[59] believes are the equivalent of the Fordham gneiss. If the two series of formations are equivalent, it is hard to understand why there should be such a marked unconformity north of the Highlands, while to the south they are apparently conformable. Evidently such a correlation is impossible the Highland gneisses are of the same age as the Fordham gneiss of southeastern New York. In this connection, however, it is interesting to note that in most of the places where the contact between the pre-Cambrian gneisses and Cambrian quartzites, schists and conglomerates is exposed in northwestern Massachusetts and western Vermont, the two formations are in apparent conformity.[60] There are other localities in this same region where they are unconformable. The work of Pumpelly, Wolff and Dale in the Green Mountains of Massachusetts showed that this conformity was only an apparent one and that the for-

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[59] *Op. cit.*, p. 361.

[60] T. Nelson Dale: Structural details in the Green Mountain region and in eastern New York. U. S. Geol. Surv. Bull. 195, p. 18. 1902.

mations were not actually continuous. At one place, two dikes of basic eruptive rock were found cutting the gneiss but not the overlying quartzite. The eruptive rock had weathered more readily than the gneiss and depressions were formed which were later filled with pebbles and sand by the advancing Cambrian sea.[61] This proved that the gneisses were of pre-Cambrian age, while the quartzite and conglomerate were known to be of Cambrian age from fossils found elsewhere in the neighboring regions. The apparent conformity evidently was only a structural one due to the general lamination forced upon the rock by the folding.

In the case of the Fordham gneiss, however, parts of which at least are of sedimentary origin, as shown by the occurrences of interbedded limestone in it, the foliation appears to be parallel to the bedding planes, as the bands of interbedded limestone are always parallel to the foliation of the gneiss.

The fact that the phyllite and schist occur so close together in the vicinity of Peekskill, which has been cited as strong evidence in favor of the later origin of the former, is not as strong an argument as one might at first think when we consider that this change does take place within a not very much greater distance north of the Highlands and also that the intrusion of the Cortland series must have had considerable effect in obliterating transition phases if they did occur. As has already been mentioned, there are still evidences present of what appear to be such transition phases.

From the above discussion, it is seen that there is still doubt as to the true age of the Manhattan schist. A much more detailed study of the geology of southeastern New York State and western Connecticut and Massachusetts than has yet been attempted will have to be made before a definite conclusion can be arrived at.

Acknowledgments. The writer is greatly indebted to Professor James F. Kemp, at whose suggestion this study of the Manhattan schist was undertaken, and to Professor Charles P. Berkey for many helpful suggestions as the work progressed. The work was carried on in the laboratories of the Department of Geology of Columbia University.

[61] U. S. Geol. Surv. Mon. XXIII, p. 11. 1894.

Bibliography

AKERLY, SAMUEL: An essay on the geology of the Hudson River and the adjacent regions; illustrated by a geological section of the country from the neighborhood of Sandy Hook, in New Jersey, northward through the High lands in New York, toward the Catskill Mountains. New York, 1820.

BASTIN, EDSON S.: Feldspar and quartz deposits of Southeastern New York. U. S. Geol. Surv. Bull. 315, pp. 394–399. 1906.

———: Feldspar deposits of Westchester Co., New York. U. S. Geol. Surv. Bull. 420, pp. 60–63. 1910.

BERKEY, CHARLES P.: Structural and stratigraphic features of the basal gneisses of the Highlands. N. Y. State Mus. Bull. 107, pp. 361–378. 1907.

———: Areal and structural geology of southern Manhattan Island. Ann. N. Y. Acad. Sci., Vol. XIX, No. 11, Part II, pp. 247–282. 1910.

———: Geology of the New York City (Catskill) Aqueduct. N. Y. State Mus. Bull. 146. 1911.

BERKEY, CHARLES P., and JOHN R. HEALY: The geology of New York City and its relations to engineering problems. Municipal Eng. N. Y. C., Pap. No. 62. 1911.

CHAMBERLIN, B. B.: The minerals of New York County, including a list complete to date. Trans. N. Y. Acad. Sci., Vol. VII, pp. 211–235. 1888.

COZZENS, ISSACHAR, JR.: A geological history of Manhattan or New York Island, together with a map of the Island, and a suite of sections, tables and columns for the study of geology. New York, 1843.

CREDNER, H.: Geognostische Skizze der Umgegend von New York. Zeits. d. Deuts. geol. Gesell., Vol. 17, pp. 388–398. 1865.

DANA, EDWARD SALISBURY: Hydrous anthophyllite of New York Island. Descriptive Mineralogy, 6th ed., p. 398. New York, 1903.

DANA, JAMES D.: Green Mountain geology on the quartzite. Am. Jour. Sci., 3rd ser., Vol. III, pp. 179–186, 250–256. 1872.

———: On the geological relations of the limestone belts of Westchester County, New York. Am. Jour. Sci., 3rd ser., Vol. 20, pp. 21–32, 194–220, 359–375, 450–456, 1880; Vol. 21, 1881, pp. 425–443; 1881, Vol. 22, pp. 103–119, 313–315, 327–335.

———: Note on the Cortland and Stony Point Hornblendic and Augite rock. Am. Jour. Sci., 3rd ser., Vol. XXVIII, pp. 384–386. 1884.

ECKEL, C. E.: The quarry industry in southeastern New York. N. Y. State Mus. Rep. 54, Vol. I, pp. 145–147. 1900.

GALE, L. D.: Report on the geology of New York County. Geol. Surv. N. Y., 3d ann. rep., pp. 177–199. 1839.

GRATACAP, L. P.: Geology of the City of New York. New York, 1909.

HALL, JAMES: Report on building stones. N. Y. State Mus. Nat. Hist., 39th ann. rep., pp. 186–225. 1886.

HAYDEN, H. H.: Description of Granite Ridge crossing New York Island. An elementary treatise on mineralogy and geology. Cleveland, 1816.

HIDDEN, W. EARL: Xeno time from New York City. Am. Jour. Sci., 3d ser., Vol. XXXVI, p. 380. 1888.

HOBBS, WILLIAM HERBERT: Origin of the channels surrounding Manhattan Island, New York. Bull. Geol. Soc. Am., Vol. 16, pp. 151–182. 1905.

———: The configuration of the rock floor of Greater New York. U. S. Geol. Surv. Bull. No. 270. 1905.

HOVEY, E. O.: Notes on some specimens of minerals from Washington Heights, N. Y. City. Am. Mus. Nat. Hist. Bull., Vol. 7, p. 341. 1895.

HUMPHREYS, EDWIN W., and JULIEN, ALEXIS A.: Local decomposition of rock by the corrosive action of pre-Glacial peat-bogs. Jour. Geol., Vol. XIX, pp. 47–56. 1911.

IDDINGS, J. P.: Hornblende schist from Manhattan Island, New York. U. S. Geol. Surv. Bull. 150, p. 331. 1898.

———: Schistose biotite gneiss from Manhattan Island, New York. U. S. Geol. Surv. Bull. 150, p. 332. 1898.

JULIEN, A. A.: Notes on the origin of the pegmatites from Manhattan Island. Sci., N. S., Vol. 12, pp. 1006–1007. 1900.

———: Genesis of the Amphibole schists and serpentines of Manhattan Island, New York. Bull. Geol. Soc. Am., Vol. 14, pp. 421–494. 1903.

———: The occlusion of igneous rock within metamorphic schists, as illustrated on and near Manhattan Island, New York. Ann. N. Y. Acad. Sci., Vol. XVI, pp. 387–446. 1906.

KEMP, J. F.: The geology of Manhattan Island. Trans. N. Y. Acad. Sci., Vol. VII, pp. 49–64. 1887.

———: On the Rosetown extension of the Cortlandt series. Am. Jour. Sci., 3rd ser., Vol. XXXVI, pp. 247–254. 1888.

———: The geological section of the East River at 70th St., New York. Trans. N. Y. Acad. Sci., Vol. XIV, pp. 273–276. 1895.

———: Pre-Cambrian formations in the State of New York. Cong. Geol. Int., Compte Rendu du XI, pp. 699–719. 1910.

KOEBERLIN, F. R.: The Brewster iron-bearing district of New York. Econ. Geol., Vol. 4, pp. 713–754. 1909.

LUQUER, LEA McI.: Bedford cyrtolite. Am. Geol., Vol. 33, pp. 17–19. 1904.

LUQUER, LEA McI., and HEINRICH RIES: The "augen" gneiss area, pegmatite veins and diorite dikes at Bedford, N. Y. Am. Geol., Vol. XVIII, pp. 239–261. 1896.

MACLURE, WM.: Geological map of the United States. An elementary treatise on mineralogy and geology. Cleveland, 1816.

MATHER, W. W.: Report of the geologist of the first geological district of the State of New York. Geol. Surv. N. Y., second ann. rep., pp. 121–183. 1838.

———: Third annual report of the geologist of the first geological district of New York. Geol. Surv. N. Y., third ann. rep., pp. 69–134. 1839.

———: Geology of New York. Part I. Comprising the geology of the first geological district. Albany, 1843.

MERRILL, FREDERICK J. H.: On the metamorphic strata of southeastern New York. Am. Jour. Sci., 3rd ser., Vol. XXXIX, pp. 383–392. 1890.

———: The geology of the crystalline rocks of southeastern New York. N. Y. State Mus., 50th ann. rep., Vol. 1, pp. 21–31. 1896.

———: The origin of the serpentines in the vicinity of New York. N. Y. State Mus., 50th ann. rep., Vol. I, pp. 32–44. 1896.

———: Metamorphic crystalline rocks of the New York Quadrangle. Geol. Atlas U. S., N. Y. C. Folio, No. 83, pp. 3–5. 1902.

MERRILL, GEORGE P.: Notes on the serpentinous rocks of Essex Co., New York, from Aqueduct Shaft 26, New York City, and from near Easton, Pennsylvania. Proc. U. S. Nat. Mus., Vol. XII, pp. 595–600. 1890.

NIVEN, WILLIAM: On a new locality for Xeno time, etc., on Manhattan Island. Am. Jour. Sci., 3rd ser., Vol. L, p. 75. 1895.

NEWBERRY, J. S.: The geological history of New York Island and Harbor. Pop. Sci. Month., Vol. 13, pp. 641–660. 1878.

———: Age of crystalline rocks of New York Island and Staten Island. Trans. N. Y. Acad. Sci., Vol. I, pp. 57–58. 1881–'82.

NEWLAND, D. H.: The serpentines of Manhattan Island and vicinity and their accompanying minerals. Sch. of Mines Quart., Vol. XXII, pp. 307–317, 399–410. 1901.

———: Bedford pegmatite quarry. N. Y. State Mus. Bull. 102, pp. 69–70. 1906.

RICE, WILLIAM NORTH: Berkshire (Hudson schist). Manual of the Geology of Connecticut, by William North Rice and Herbert Ernest Gregory. Conn. Geol. and Nat. Hist. Surv. Bull. No. 6, p. 91. 1906.

RIES, HEINRICH: Note on rock exposure at 143rd Street and 144th Street and Seventh Avenue, New York City. Trans. N. Y. Acad. Sci., Vol. 10, pp. 113–114. 1891.

RIGGS, R. B.: The so-called Harlem indicolite. Am. Jour. Sci., 3rd ser., Vol. XXXIV, p. 406. 1887.

ROGERS, G. S.: Original gneissoid structure in the Cortland Series. Am. Jour. Sci., Vol. XXXI, pp. 125–130. 1911.

———: Geology of the Cortland Series and its emery deposits. Ann. N. Y. Acad. Sci., Vol. XXI, pp. 11–86. 1911.

SMITH, J. LAWRENCE, and G. J. BRUSH: Hydrous anthophyllite from New York Island. Am. Jour. Sci. and Arts, Vol. XVI, p. 49. 1853.

SMOCK, JOHN C.: A geological reconnaissance in the crystalline rock region, Dutchess, Putnam and Westchester counties, New York. N. Y. State Mus. Nat. Hist., 39th ann. rep., pp. 166–185. 1886.

STEVENS, R. P.: Report upon the past and present history of the geology of New York Island. Ann. N. Y. Lyceum Nat. Hist., Vol. VIII, pp. 108–120. 1867.

VAN HISE, CHAS. R., and CHARLES K. LEITH: Pre-Cambrian geology of North America. U. S. Geol. Surv. Bull. 360, pp. 622–635. 1909.

WHITLOCK, H. P.: List of New York mineral localities. N. Y. State Mus. Bull. 70. 1903.

WILLIAMS, GEORGE H.: Peridotites of the Cortlandt Series. Am. Jour. Sci., 3rd ser., Vol. XXXI, p. 26. 1886.

———: The norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y. Am. Jour. Sci., 3rd ser., Vol. XXXIII, pp. 135–144, 191–199. 1887.

———: The contact-metamorphism produced in the adjoining mica schists and limestones by the massive rocks of the "Cortlandt Series" near Peekskill, N. Y. Am. Jour. Sci., 3rd ser., Vol. XXXVI, pp. 254–269. 1888.

———: The gabbros and diorites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y. Am. Jour. Sci., 3rd ser., Vol. XXXV, pp. 438–449. 1888.

PLATE VIII

HORNBLENDE SCHIST AND EPIDOSITE

FIG. 1. Hornblende schist sheet in Manhattan schist.
Near W. 160th Street and Edgecomb Avenue, New York City.

FIG. 2. Epidosite in hornblende schist.
The two middle bands between the light bands are epidosite.
South shore, Croton Lake, New York.

1

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PLATE IX

PEGMATITE DIKES

Fig. 1. Pegmatite dike in Inwood limestone.
West 204th Street, east of Sherman Avenue, New York City.

Fig. 2. Banded pegmatite dike in Manhattan schist.
Speedway at Ft. George, New York City.

1

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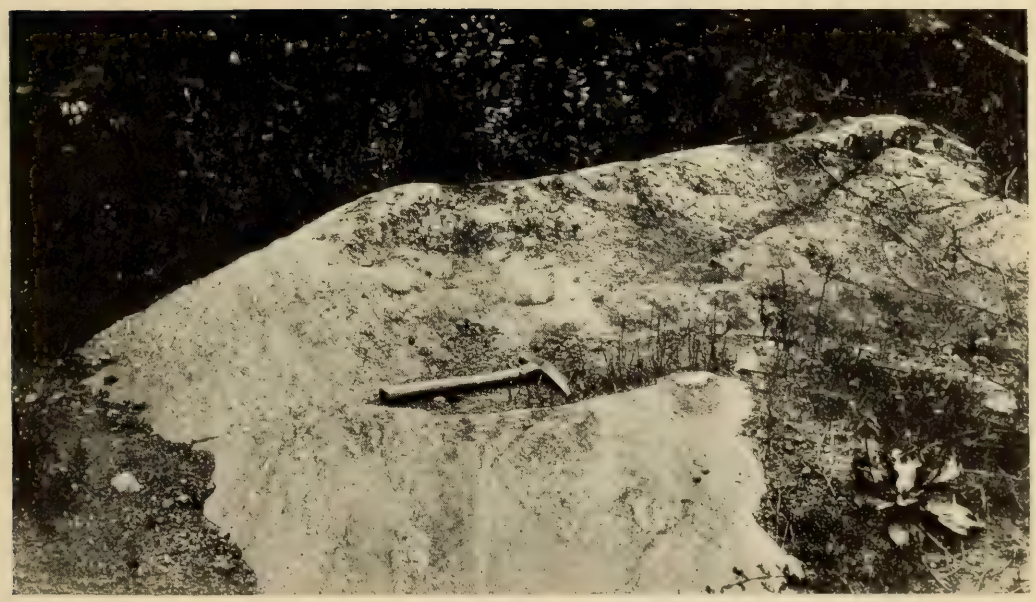
PLATE X

MANHATTAN SCHIST AND AUGEN GNEISS

Fig. 1. Manhattan schist injected with pegmatite.
Near Rye, Westchester County, New York.

Fig. 2. "Augen" gneiss.
South of Bedford Village, Westchester, New York.

1



2

PLATE XI

SPECIMENS OF AUGEN GNEISS

FIG. 1. "Augen" gneiss.
South of Bedford Village, Westchester County, New York.

FIG. 2. "Augen" gneiss.
South of Bedford Village, Westchester County, New York.

1

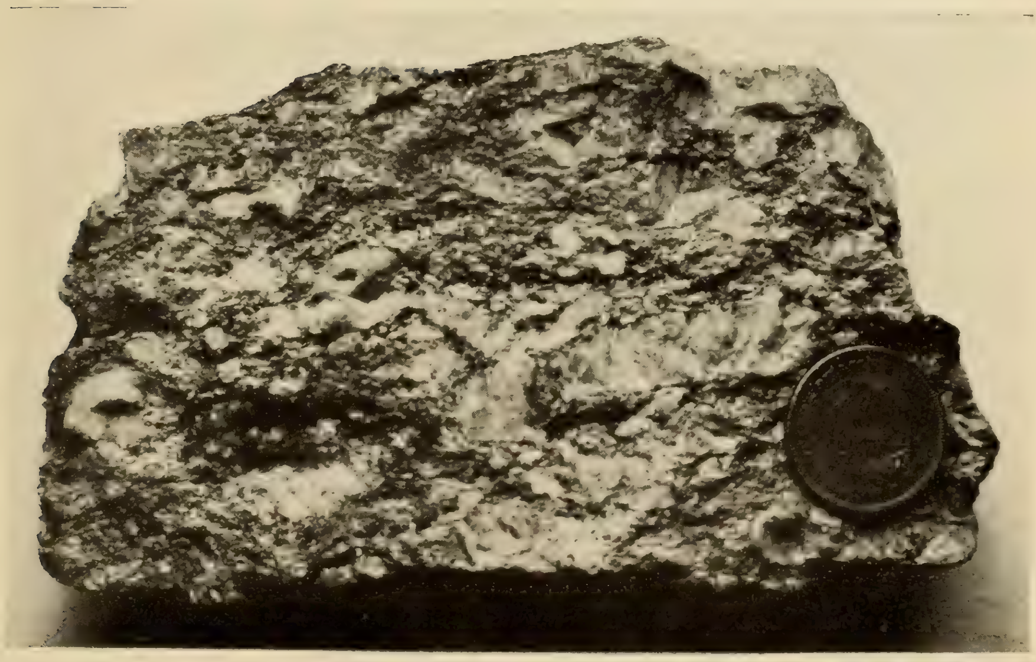


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PLATE XII

PHOTOMICROGRAPHS OF GNEISS, SCHIST AND GRANODIORITE

Fig. 1. Interbedded gneiss.
Catskill Aqueduct tunnel underneath Harlem River at High Bridge, New York City.
Magnified 22.5 diameters. Crossed nicols.

Fig. 2. Fordham gneiss.
East of High Bridge, New York City.
Magnified 22.5 diameters. Crossed nicols.

Fig. 3. Cyanite schist.
West 120th Street, east of Amsterdam Avenue, New York City.
Magnified 22.5 diameters. Crossed nicols.

Fig. 4. Hornblende schist.
South shore, Croton Lake, New York.
Magnified 22.5 diameters.

Fig. 5. Harrison granodiorite.
Greenwich, Connecticut.
Magnified 22.5 diameters.


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4
5

PLATE XIII

PHOTOMICROGRAPHS OF SCHIST

FIG. 1. Mica-feldspar-quartz schist.
Southeast corner West 116th Street and Broadway, New York City.
Magnified 22.5 diameters.

FIG. 2. Gray gneissoid variety of schist.
West 42nd Street, near 5th Avenue, New York City.
Magnified 22.5 diameters. Crossed nicols.

FIG. 3. Mica schist.
Verplanck, Westchester County, New York.
Magnified 22.5 diameters. Crossed nicols.

FIG. 4. Mica schist.
North of Croton-on-the-Hudson, Westchester County, New York.
Magnified 22.5 diameters.

FIG. 5. Staurolite mica schist.
North of Croton-on-the-Hudson, Westchester County, New York.
Magnified 22.5 diameters.


1
2
3
4
5

PLATE XIV

PHOTOMICROGRAPHS OF PHYLLITE AND SCHIST

FIG. 1. Phyllite.
East of Peekskill Creek Valley, New York.
Magnified 22.5 diameters. Crossed nicols.

FIG. 2. Phyllite.
East of Clove Valley, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.

FIG. 3. Mica schist.
West of Wingdale, Dutchess County, New York.
Magnified 22.5 diameters.

FIG. 4. Staurolite mica schist.
West of Wingdale, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.

FIG. 5. Mica-feldspar-quartz schist.
East of Pawling, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.

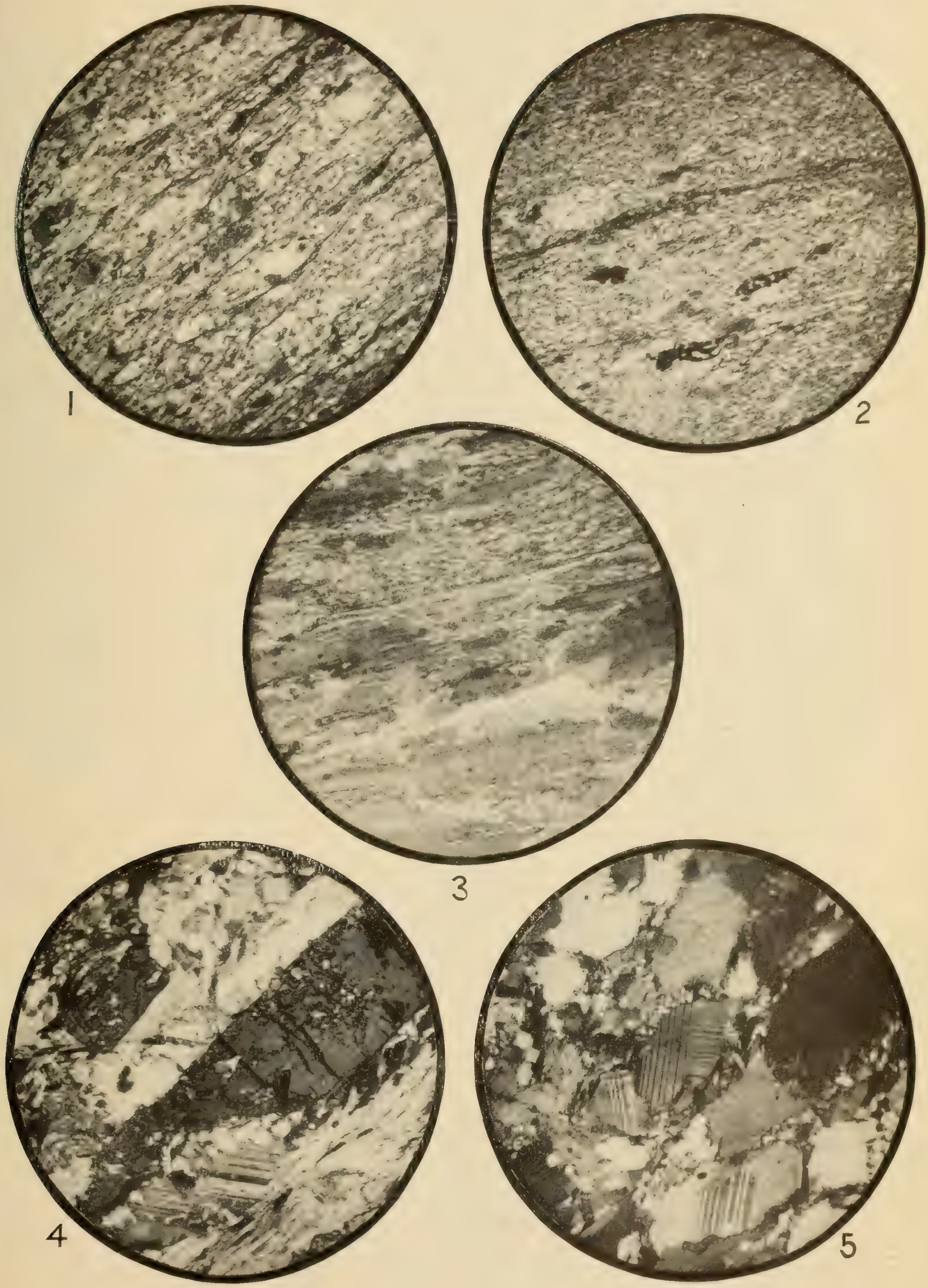
1
2
3
4
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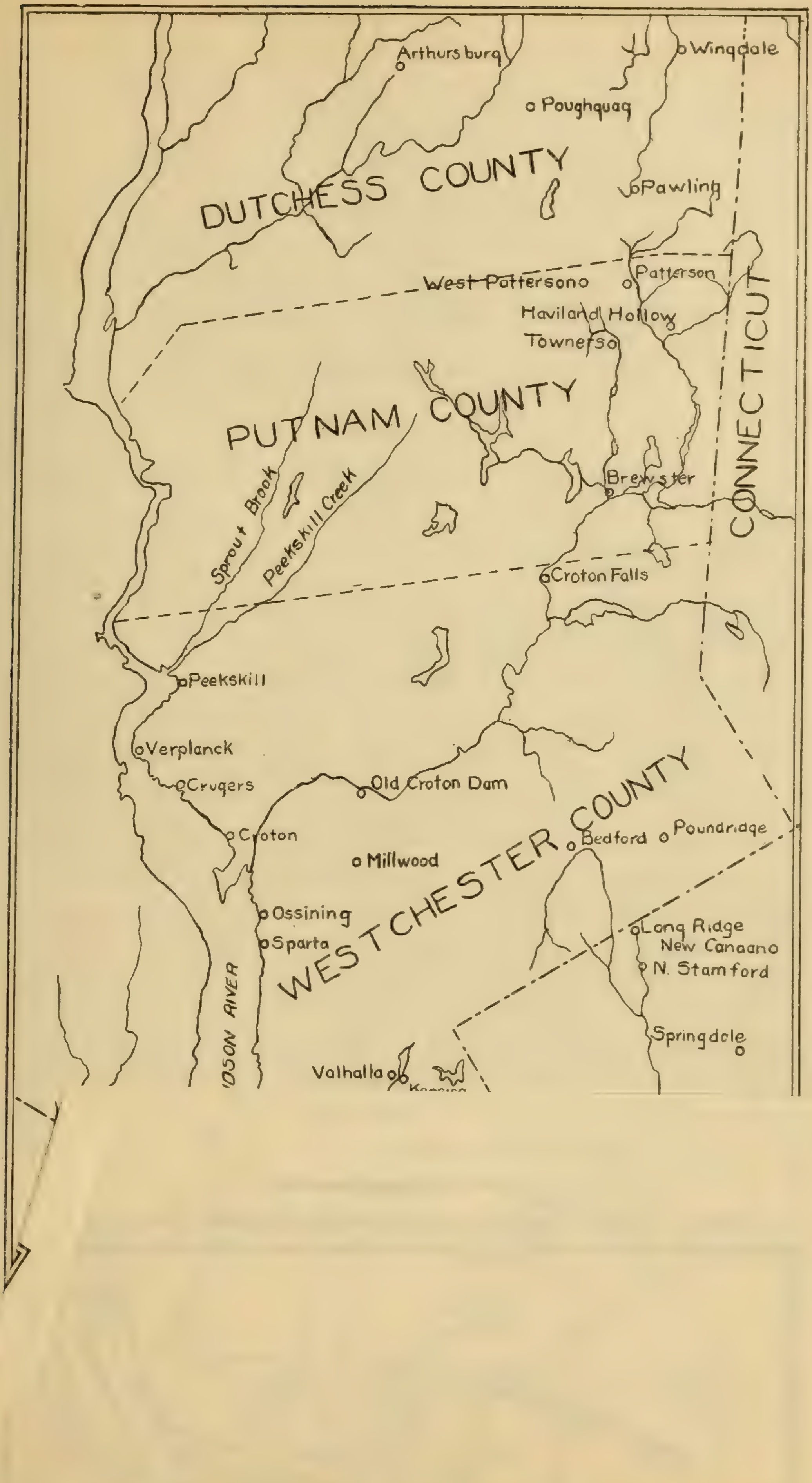
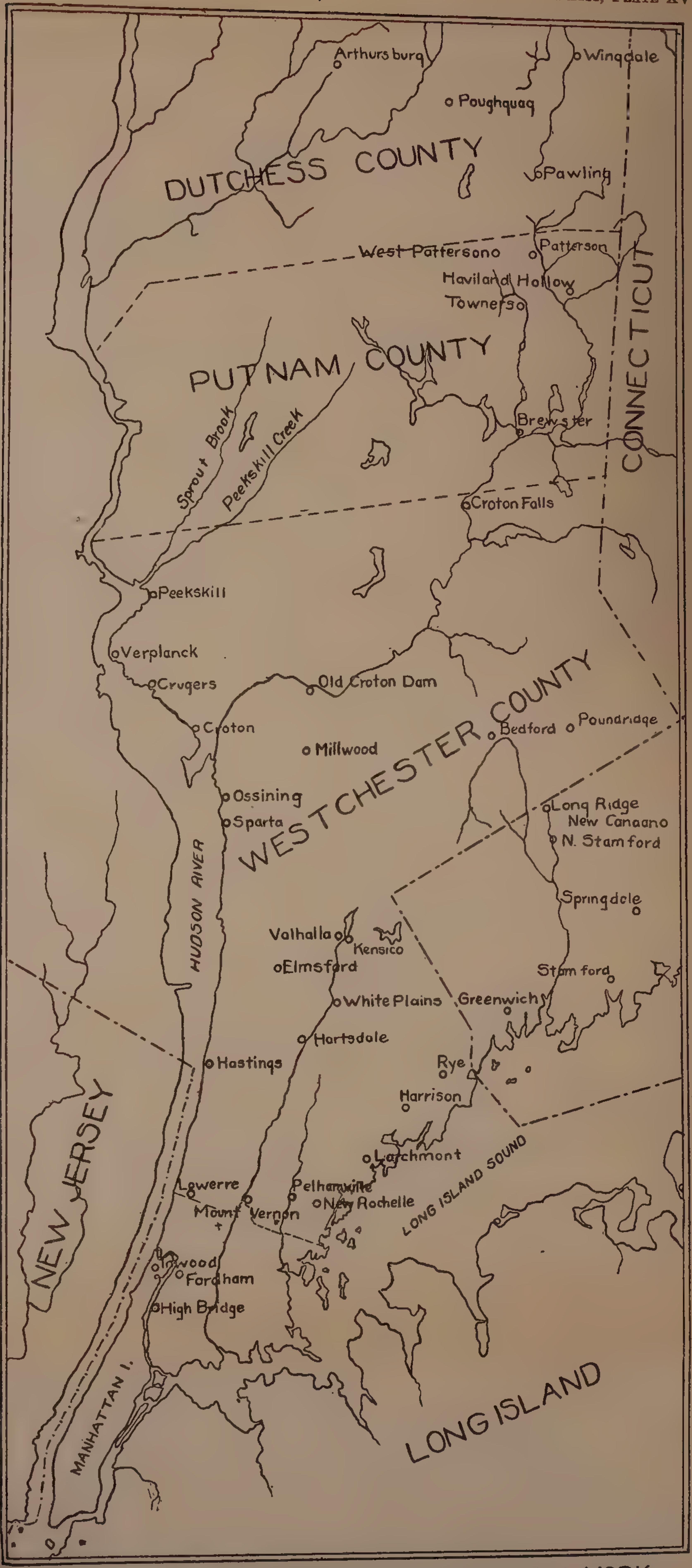
PLATE XV

OUTLINE MAP OF SOUTHEASTERN NEW YORK


Arthursburg
Wingdale
Poughquag
DUTCHESS COUNTY
Pawling
West Patterson
Patterson
Haviland Hollow
Towners
PUTNAM COUNTY
CONNECTICUT
Sprout Brook
Peekskill Creek
Brewster
Croton Falls
Peekskill
Verplanck
Crugers
Old Croton Dam
Croton
Millwood
Bedford
Poundridge
WESTCHESTER COUNTY
Ossining
Sparta
Long Ridge
New Canaan
N. Stamford
Springdale
HUDSON RIVER
Valhalla



OUTLINE MAP OF SOUTHEASTERN NEW YORK.

5 0 5 Miles

PUBLICATIONS

OF THE

NEW YORK ACADEMY OF SCIENCES

(Lyceum of Natural History, 1817–1876)

The publications of the Academy consist of two series, viz.:

(1) The **Annals** (octavo series), established in 1823, contain the scientific contributions and reports of researches, together with the records of meetings and similar matter.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Vol. XXIII, pp. 261–353

Editor, Edmund Otis Hovey

RECORDS OF MEETINGS

CHARTER, CONSTITUTION AND MEMBERSHIP IN 1913

OF THE

NEW YORK ACADEMY OF SCIENCES

WITH INDEX TO VOLUME XXIII

Smithsonian Institution
JUN 18 1914
National Museum

NEW YORK
PUBLISHED BY THE ACADEMY
30 April, 1914

THE NEW YORK ACADEMY OF SCIENCES

(Lyceum of Natural History, 1817-1876)

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SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

Chairman—Wendell T. Bush, 1 West 64th Street

Secretary—Robert H. Lowie, American Museum

The sessions of the Academy are held on Monday evenings at 8:15 o'clock from October to May, inclusive, at the American Museum of Natural History, 77th Street and Central Park, West.

[Annals N. Y. Acad. Sci., Vol. XXIII, pp. 261–353. 30 April, 1914]

RECORDS OF MEETINGS

OF THE

NEW YORK ACADEMY OF SCIENCES

January to December, 1913

By Edmund Otis Hovey, *Recording Secretary*

BUSINESS MEETING

6 January, 1913

The Academy met at 8:21 p. m. at the American Museum of Natural History, Vice-President J. E. Woodman presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary then reported the following deaths:

John B. Marcou, Active Member since 1906, died 18 July, 1912,
James Terry, Active Member since 1881, died 17 October, 1912.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

6 January, 1913

Section was called to order at 8:25 p. m., Vice-President J. E. Woodman presiding.

No business was transacted, and the meeting was devoted to the following lecture:

Prof. D. W. Johnson: The Shoreline of Cascumpeque Harbor, Prince Edward Island.

Summary of Paper

Professor **Johnson,** after presenting, with the aid of blackboard maps and sketches, the criteria for distinguishing between real and apparent oscillations of shorelines, further illustrated the discussion with lantern views of actual conditions, explained where necessary by means of diagrams thrown on the screen. He showed how such events as the slumping of soft formations near the shoreline or the widening of inlets so as to increase the tidal flow into a lagoon, thus allowing a local rise of the high-tide level or the ingress of salt-water by sheer wave-cutting into fresh water swamps might be misinterpreted to mean subsidence of the land area involved. He showed that stability is indicated by evidences of growth in place of long-life vegetation at the present high-tide level and by the building of a series of beaches on a level with those now in process of formation. The speaker concluded that the area under discussion is probably the best example of features normally produced by subsidence of a maturely dissected plain to be found on our Atlantic seaboard. He finds no evidence, however, that indicates subsidence in geologically recent times; that is, within the last 2,000 years.

The paper was followed by an interesting questionnaire, during which Professor Johnson presented still other evidences bearing out his conclusions as to the duration of stable conditions and made brief applications to other localities along the Atlantic coastline of North America.

The programme was concluded by notices of important papers given at the New Haven meeting of the Geological Society of America, December 28–31, 1912. Ten minutes were devoted to each of the groups—paleontology, economic geology and petrology. Professor A. W. Grabau paid extensive attention to the proposed revision of nomenclature of the Paleozoic. Professor James F. Kemp called particular attention to the marvelous petroleum wells of northeastern Mexico, to the confirmation by Dr. A. L. Day of aqueous volcanic emanations and to the researches of Professor Jeffrey by means of his unique thin sections into the origin of coal. Mr. Charles T. Kirk reviewed Dr. Fenner's determinations of the thermometric values of the forms of silica, Professor Lane's observations on granite, etc., in the metamorphic cycle and the excellent advances made by Dr. F. E. Wright and Professor Charles P. Berkey in methods of teaching petrography, especially to beginners.

The meeting, though technical, was characterized by a good attendance, about 45 persons being present.

The Section then adjourned.

Charles T. Kirk,
Secretary.

SECTION OF BIOLOGY

13 January, 1913

Section met at 8:15 p. m., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

Dr. W. K. Gregory was elected secretary of the Section for the ensuing year.

The following programme was then offered:

W. D. Matthew, Notes on Cuban Fossil Mammals.

Barnum Brown, Remarks on the Occurrence and Discovery of Cuban Fossil Mammals.

Walter Granger, Lower Eocene Faunæ of Northwestern Wyoming.

W. D. Matthew, A Zalambdodont Insectivore from the Basal Eocene of New Mexico.

Summary of Papers

Dr. **Matthew** exhibited and described skulls and other skeletal material of *Megalocnus* Leidy and allied genera, secured by Mr. Barnum Brown with the coöperation of Professor de La Torre. He discussed the problem relating to the time and manner in which the peculiar mammalian fauna of Cuba had been derived. The most probable hypothesis, he thought, was that the remote ancestors of these mammals had come from South America, possibly having been preserved alive on one of the great natural rafts from the great rivers which sometimes drift from Brazil and Guinea toward Cuba.

Mr. **Brown** exhibited stereopticon views illustrating the mode of occurrence and discovery of the fossils. The best remains of *Megalocnus* and allied types had been secured in a hot spring near Barros de Ciego, Montero, Cuba.

Mr. **Granger** said in abstract: The extensive explorations by American Museum expeditions in the Lower Eocene formations of Wyoming have resulted in making known a nearly complete and uninterrupted series of faunal horizons from the Fort Union to the Bridger. Four new horizons have been made known: from the Wind River series, the Lost Cabin and Lysite horizons and from below the Wasatch an intermediate, unnamed horizon and the Ralston. The faunæ of each of these were described.

Dr. **Matthew** said in extract: This very precious fossil skull was discovered last summer by Mr. Walter Granger. It was an undoubted

Zalambdodont, apparently somewhat more primitive than any now living, and carried back the record for this group to the basal Eocene. The skull and dentition have been prepared with great skill by Mr. A. E. Anderson.

The Section then adjourned. William K. Gregory, *Secretary.*

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

27 January, 1913

With the consent of the Council of the New York Academy of Sciences, the American Ethnological Society invited Professors MacCurdy, Keller, Bishop, Huntington and Bowman, all of Yale University, to attend a joint meeting of the Society and the Section of Anthropology and Psychology, for the purpose of exchanging views on the problem of the influence of geographical environment on human culture. Owing to the number of papers offered, an afternoon meeting was arranged for in addition to the customary evening session, General James Grant Wilson presiding at the former and Professor Franz Boas at the latter.

The following programme was offered:

Afternoon Session

A. G. Keller, Natural Sciences as the Basis of the Social Sciences.

The reading of this paper was followed by a lecture, illustrated with lantern slides,

George Grant MacCurdy, Pre-neolithic Environment in Europe.

Evening Session

Avard L. Bishop, Race Characteristics Versus Natural Environment in Commercial Success.

Ellsworth Huntington, Climatic Influences in Human Activity.

Isaiah Bowman, The Physiographic Environment of the Machiganga Indians of Peru.

Finally, Dr. Wissler, as the representative of the American Ethnological Society, dealt with the following subject:

Clark Wissler, Culture and Environment.

The Section then adjourned. R. H. Lowie, *Secretary.*

BUSINESS MEETING

3 February, 1913

The Academy met at 8:25 p. m. at the American Museum of Natural History, President Emerson McMillan presiding.

In the absence of Dr. Hovey, Professor Kemp was appointed Secretary *pro tem.*

The minutes of the last business meeting were read and approved.

The Secretary *pro tem.* announced the following deaths:

E. H. Paddock, Active Member since 1907, died 9 December, 1912,
A. C. Goodwin, Active Member since 1910, died 17 March, 1912,
J. R. Planten, Active Member since 1907, died 8 December, 1912,
G. S. Scott, Active Member since 1907, died 2 March, 1912.

The Academy then adjourned.

J. F. Kemp,
Secretary pro tem.

SECTION OF GEOLOGY AND MINERALOGY

3 February, 1913

Section was called to order at 8:20 p. m., Vice-President J. E. Woodman presiding.

The reading of the minutes was dispensed with, and no business being transacted the meeting was at once turned over to the following lecture:

F. H. Newell, Home Making in the Arid West.

Summary of Paper

Mr. **Newell,** Chief of the U. S. Reclamation Service, was introduced by the Chairman and spoke about many of the problems of irrigation in our arid and semi-arid regions. He showed in a very constructive manner how the United States irrigation engineers must be able to handle a manifold situation. In many instances, the determination of the flood water possibilities, the areal survey of the project and the installation of the dam are coupled directly with such considerations as soil survey, building and running a cement plant, constructing and managing a railroad for passenger as well as freight traffic, generating and subletting electric power from the flood water spilling over the dams, providing for workmen in isolated settlements—even to furnishing them amusements in the way of motion-picture shows—and dealing with Indian tribes to the extent of inducing the men to work; all these and other institutions and functions being either owned or controlled by the Reclamation Service of the United States Government.

To carry on the various projects requires the expenditure of some twelve million dollars annually, or about a million a month. When the score or more of projects have all been completed, homes on the farms and in the villages of the arid West will be provided for more than two million families.

The fallacy of dry farming was clearly shown by the loss of about one farm crop in three through that practice.

The lecture was splendidly illustrated with polychrome slides of very characteristic western views.

Owing to unpleasant weather, only 75 persons attended. These were further entertained by Mr. Newell's informal replies to questions from members and visitors after the formal presentation of the subject.

The Section then adjourned.

Charles T. Kirk,
Secretary.

SECTION OF BIOLOGY

10 February, 1913

Section met at 8:15 p. m., Dr. F. A. Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Louis Hussakof, The Pleuracanthid Sharks with Special Reference to the Cranium.

John T. Nichols, Correlation of Body- and Fin-form with Habit in Recent Fishes.

William K. Gregory, Locomotive Adaptations in Fishes Illustrating "Habitus" and "Heritage."

Summary of Papers

Dr. **Hussakof** exhibited a life-sized model of *Pleuracanthus*, based on the material figured by Brongniart and Fritsch, together with original material and wax models of the skulls of the allied *Diacranodus* from the Permo-Carboniferous of Texas. The speaker pointed out that Cope and other authors had mistaken the ventral for the dorsal surface of the skull and the cotylus of the nuchal spine for the foramen magnum. Removal of the hard matrix by etching has revealed the principal foramina and other details of the numerous well-preserved skulls. The Pleuracanths must be regarded as highly specialized rather than primitive Elasmobranchs.

Mr. **Nichols's** paper was illustrated with lantern slides.

Dr. **Gregory** reviewed some of the evidence which had led him to the following conclusions regarding the evolution of the locomotive organs:

(1) That myomeres, or contractile cœlomic, mesodermal pouches are the oldest and most essential part of the locomotive apparatus.

(2) That the differentiation, concrescence and other modifications of the myomeres have determined corresponding differentiations, concentrations, etc., in the nervous system; not *vice versa.*

(3) That, with the possible exception of the notochord, the endoskeletal structures have all been determined as to their origin by the arrangement and function of the myomeres and of the interjacent myocommas, not *vice versa.*

(4) That the acquisition of a many-layered skin capable of secreting hard deposits of calcified cartilage or of bone was a critical stage in the evolution of the vertebrates, because it permitted the formation of exoskeletal structures (scales, surface bones, dermal rays), originally protective, which afterward became functionally connected with the locomotive apparatus. The primitive scales themselves may represent highly modified sense organs.

(5) That the earliest fins were mere folds of skin or ridges on the body, serving as keels at nodal points, in connection with flexures of the body.

(6) That the myomeres were either originally or secondarily produced into the fin-base and that rod-like cartilages were laid down in the connective tissue areas between the myomeres.

(7) That both the median and paired fins were originally broad-based, the basal cartilages lying wholly within the body-line; but as the fins acquired independent motion, the basal cartilages became widely protruded, changing the fins into the various paddles, either with a wide fin-web or a reduced fin-web.

(8) That uniserial or mesorhacic fins were independently evolved in the Crossopterygii and Dipnoi and that the broad-based fins of other fishes were in no sense derived from the mesorhachic type.

(9) That the limbs of Tetrapods were evolved from paddles with widely protruded basals which were of spreading or fan-shape, as in *Sauripteris.*

The following definitions of habitus and heritage were given:

The habitus of a race of fishes is the totality of their cænotelic characters, *i. e.,* of all those characters which have been evolved in adaptation to their latest habits and environment.

The heritage of a race of fishes is the totality of their palæotelic characters, *i. e.,* of all those characters which were evolved in adaptation to earlier habits and environments and which were transmitted in a more or less unchanged condition, in spite of later changes in habits and environment.

The locomotive apparatus of all fishes affords illustrations of the conceptions designated as habitus and heritage, *e. g.,* the habitus of *Lepidosiren* is eel-like, its heritage is Dipnoan; the habitus of Lampreys is also more or less eel-like, but their heritage is with the Cyclostomes; the habitus of *Thoracopterus,* a fossil Ganoid described by Abel, is much like that of the true flying fishes (Exocœtidæ), but its heritage is that of the Pholidophoridæ.

The habitus of a race tends to conceal its remote phylogenetic relationships; the heritage reveals them. Cænotelic and palæotelic, habitus and heritage, are correlative terms. A palæotelic character becomes cænotelic through a change of function.

This paper was illustrated with lantern slides.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

24 February, 1913

The Section met in conjunction with the New York Branch of the American Psychological Association, Professor R. S. Woodworth presiding.

The following programme was offered:

F. Krueger,	Difference Tones and Consonance.
Raymond Dodge,	The Attempt to Measure Mental Work as a Psycho-Dynamic Process.
Robert M. Yerkes,	The Psychology of the Earthworm.
John B. Watson,	Psychology as the Behaviorist Views It.
C. C. Trowbridge,	Methods of Orientation and Imaginary Maps.
C. C. Trowbridge,	The Probable Explanation of Certain Flock Formations of Birds.

F. Lyman Wells, A Note on the Retention of Practice.
Darwin Oliver Lyon, A Comparative Study of the Illusions and Hallucinations of Dementia Præcox and Manic Depressive Insanity.

Summary of Papers

Dr. **Krueger's** paper has been published on page 158 of Volume X of the *Journal of Philosophy.*

Dr. **Dodge's** paper has been published in the *Psychological Review* for January, 1913.

Dr. **Yerkes** said: This is a preliminary report of an investigation, now in progress, the purpose of which is (*a*) to demonstrate whatever ability the earthworm may have to acquire habits of a certain order; (*b*) to discover the characteristics of any habits which appear; (*c*) to enumerate and evaluate the various external and internal influences on habit-formation; (*d*) to ascertain the degree of permanency of the habits, and (*e*) to discover their relations to the anterior ganglia (brain).

By means of a T-shaped maze constructed from plate glass, specimens of the manure worm, *Allolobophora fœtida,* were tested. The maze was placed with the stem directed toward the light. Across one of the arms a piece of sandpaper was placed and, just beyond it, a pair of electrodes. The other arm was left open so that the worm might escape to an artificial burrow. The worms were driven into the T by light and the chief motive for escape therefrom was the tendency to avoid light. It was the purpose of the test to demonstrate (*a*) any ability which the manure worm may possess to acquire a direction-habit and (*b*) to associate the tactual experience of contact with sandpaper with the electrical shock which regularly followed the tactual stimulus in case the worm continued to move forward after reaching the sandpaper.

Trials were made in daily series varying in number from 5 to 20. The 5-trial series were found, on the whole, more satisfactory.

Referring now exclusively to the results obtained for a single worm which has been under observation since October, 1911, the following results may be presented: (1) *Allolobophora* is capable of acquiring certain definite modes of reaction. (2) Modifications appear as the result of from 20 to 100 experiences. (3) The behavior is extremely variable because of variations in external conditions and in the condition of the worm itself. (4) There is a tendency to follow the mucous path through the apparatus, but this is not sufficiently strong or constant to yield perfect results. (5) The following are the chief modifications which have been noted: (*a*) increased readiness to enter the apparatus and to desert it for the artificial burrow; (*b*) apparent "recognition" of the artificial burrow which is used as "*exit tube*"; (*c*) a gradual increase in the number of avoidances of the sandpaper and of contact with the electrodes as a result of the "warning" influence of the sandpaper; (*d*) the disappearance of the early tendency to retrace the path through the stem of the T; (*e*) the similar disappearance of the tendency to turn back after progressing well toward the exit tube. (6) The correct performance of a thoroughly ingrained habitual act, of the kind studied in this investigation, is not dependent upon the "brain" (portions of the nervous system carried by the five anterior segments), since the worm reacts appropriately within a few hours after its removal. (7) As the brain regenerates, the worm exhibits increased initiative, its behavior becomes less automatic, more variable. (8) Within four weeks after the operation the regenerated segments appear superficially complete and the worm naturally burrows in a mixture of earth and manure. (9) Two months after the removal of the "brain," during the last four weeks of which period no training was given, the habit had completely disappeared from worm No. 2, the subject to whose responses this paper is devoted, and in its place there appeared a tendency to turn in the opposite direction to that demanded in the training. (10) Systematic training for two weeks resulted in the partial reacquisition of the original direction-habit.

The general results which have just been stated are subject to modification in the light of additional data. To the experimenter it seems that the particular individual which has been longest under observation is in many respects exceptional. It is perfectly clear, however, from results obtained with other individuals that important modifications in behavior appear as the result of training. It is equally certain that direction-habits are not readily acquired.

Dr. **Watson's** paper has been published in the *Psychological Review* for March, 1913.

Professor **Trowbridge** classified the methods of orientation under two heads. The first was called the *domi-centric method,* used by all living creatures except man in a civilized state. In this case the manner of moving about the surface of the earth relates to a point, usually the home. In the second type, which was called the *ego-centric method,* or cardinal-point method, the use is made of the cardinal points of the compass to give orientation, and those points do not necessarily relate to any particular center or home. It is believed that those creatures using a *domi-centric* method have an advantage over civilized man in finding their way home. There may be readily a combination of the two methods in special cases.

In the second part of the paper it was shown that a very large percentage of people, amounting to the order of 50 per cent, are accustomed to *think* of far distant places in an entirely different direction than they really are, amounting to from 45° to 180° from the real direction. The subjects tested *knew* the correct direction within a few degrees. Statistics seem to indicate that individuals having these "imaginary maps" were more apt to be confused with respect to direction than those not having them.

Dr. **Trowbridge's** second paper also consisted of two parts, and in the first the author showed that birds in a large flock when migrating, in all probability, average their errors with respect to a certain distant destination, and if this is the case the explanation of the migration in large flocks of many species of birds can be explained, also; the principle would prevent single birds from going astray.

The second part of the paper related to the echelon formation of flight of many large birds when flying in flocks; the explanation given being that it is the most protective arrangement. Evidence was brought forward to show that in this formation the birds in the flock can see forward as well as to the side, these regions are the chief "danger zones" that the flying flock is subjected to. The paper was illustrated by diagrams, and by photographs of blue geese taken by Mr. Herbert K. Job at Marsh Island, on the Mississippi delta.

Dr. **Wells** said in abstract: One subject was highly practised in the tapping test 5½ years ago. Six other subjects were highly practised in addition and number-checking tests nearly 3 years ago. The present experiments were made to ascertain the amount and character of the loss during the relative disuse of the functions. In all tests the loss found was about half the percentile amount gained by practice. The renewal of practice does not bring with it an especially rapid practice gain. Persons who gain much in the addition test regularly tend to lose much in it, but this is not true in the number-checking test. Persons who lose much in the one test, however, tend also to lose much in the other, although the amounts of practice gain in them are negatively related.

Dr. **Lyon** said in abstract: The various conceptions of the terms *hallucination* and *illusion* were taken up in detail and it was shown that, although no sharp line of demarcation could be drawn between the two terms, yet the distinction was sufficiently fine to warrant their separation in an experiment such as the one under consideration. An hallucination was defined as a subjective sensory image arising without the aid of external stimuli, or, in short, a perception without an object. Illusions were defined as the false interpretation of external objects; *i. e.,* an illusion is the falsification of a real percept. The speaker admitted that cases might occur in which ideas originating wholly in the cortical center might become so vivid as to be taken for sensations that had arisen by stimulation of the sense organs—but he believed that these cases were much less common than is generally supposed.

It was shown that the various authorities differed greatly as to the frequency of hallucinations and illusions in the various forms of insanity. Each of the various psychoses were considered. In *dementia paralytica,* for example, the elder Falret absolutely denied their existence. Kraft-Ebbing says they are so rare that where they are found one should suspect a false diagnosis. Yet Jung, Saury, and Mickle concur in saying that they occur in over one half of all cases.

The part that the various senses play in the fallacious perceptions of the insane was then considered. Though this depends somewhat on the psychosis, both hallucinations and illusions of *hearing* are much more frequent than those of any of the other senses or even combination of the senses. In one form of mania sight hallucinations were found to be greater in number than auditory hallucinations. Hallucinations of taste are very rare. The speaker considered it doubtful if the so-called gustatory hallucinations occasionally seen in *dementia paralytica* were true hallucinations. His experience led him to believe that they were rather the *result* of delusions, in that when a delusion was being "described" by a patient he naturally made his ideas and feelings "fit" accordingly. Of the 361 cases of *dementia prœcox* and *maniac depressive insanity* tested, only 4 were found having fallacious perceptions of taste, either alone or in combination.

In some cases, the patient informs the physician of his own accord regarding his hallucinations and illusions; in others, the information sought for must be obtained by some roundabout method. Care must be taken that reported hallucinations are not really illusions; for example, when in a noisy ward a patient hears herself being called a witch, it is difficult to decide whether she is experiencing an hallucination or an illusion. When, however, the morbid perception occurs in absolute silence we may feel reasonably certain that the patient experiences an hallucination. It was shown that in those cases in which the patient is suspected of endeavoring to conceal the fact that he experiences hallucinations, considerable work may be necessary before their presence or absence can be definitely determined. Careful observation of the patient when he is unaware that he is being watched is, of course, necessary in many cases.

Turning the head in a certain direction to listen, gazing at a certain portion of the wall and speaking to it, stuffing the ears with cloth or paper—these and many other "symptoms" lead us to suspect the existence of hallucinations. Evidence of strong emotion, expressions of hate, fear, etc., though not of themselves evidence of hallucinations, warrant further search. The entire test consisted of the following: (1) An examination of the patient's "history." (2) Conversation with the physician and attendants in charge. (3) Various questions and tests varied to suit the case. The question concerning the extent to which we should try to *elicit* hallucinations in an experiment of this nature was taken up in detail.

Tables were then presented showing the results of the tests and conclusions drawn. Of the 173 cases of *dementia præcox* 100, *i. e.,* 58 per cent, had fallacious perceptions; of these, 87 were hallucinations; 8, illusions, and 5 hallucinations and illusions. Of the 188 cases of *manic depressive insanity* 64, *i. e.,* 34 per cent, had fallacious perceptions; of these, only 9 were hallucinations, whereas 51 were illusions. Space does not permit a tabulation of the 18 groups into which the speaker assembled his cases. Suffice it to say that hallucinations and illusions of *hearing* come first—comprising, as they do, over one half of all cases. Then come *hearing* combined with *sight,* and then those of *sight* alone. The other senses, either alone or in combination, were but sparsely represented.

The meeting then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

3 March, 1913

The Academy met at 8:23 p. m. at the American Museum of Natural History, President Emerson McMillin presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary reported the following death:

Walter H. Mead, Active Member since 1882 (Patron since 1888).

The following candidate for Active Membership in the Academy, recommended by Council, was duly elected:

G. G. Scott, College of the City of New York.

The Academy then adjourned.

E. O. Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

3 March, 1913

Section was called to order at 8:20 p. m., Vice-President J. E. Woodman presiding.

The minutes of the previous meeting were read and approved.

Vice-President Woodman called President McMillin to the chair, and the following programme was then offered:

J. E. Woodman, The Interbedded Iron Ores of Nova Scotia.

Summary of Paper

Professor **Woodman** elaborately illustrated the field evidence by lantern views and hand specimens, some half a hundred of each. The net results seemed fairly to warrant a modified form of the replacement theory as an explanation of these deposits.

Professor Kemp commented upon the new evidence in the light of the interesting body of data which seemed to argue somewhat in opposition to the findings of Professor Woodman, as presented by workers in other regions, and concluded with an invitation for remarks by Professor Van Ingen, of Princeton University, a former officer of the New York Academy of Sciences. Professor Van Ingen stated that the results of his investigations into the iron-ore deposits of Newfoundland were as yet inhibitive, but that he had found extremely probable evidence of Paleozoic faunal connection between Newfoundland and certain European localities.

The Section then adjourned.

Charles T. Kirk,
Secretary.

SECTION OF BIOLOGY

10 March, 1913

Section met at 8:15 p. m., Dr. F. A. Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Charles Packard, The Influence of Radium on the Fertilization of the Egg of Nereis.

George G. Scott, Osmotic and Other Relations of Aquatic Animals to the External Medium.

George G. Scott, A Physiological Study of the Changes in *Mustelus canis* produced by Modifications in the Molecular Concentration of the Experimental Medium.

Summary of Papers

Dr. **Packard's** paper is to be published in the Journal of Experimental Zoölogy.

In his first paper, Dr. **Scott** summarized his own and other investigations on osmotic pressure of the tissues in aquatic animals. In marine invertebrates, he said, the internal osmotic pressure varied with that of the external medium; in the higher fishes, it was more stable, responses to changes in the medium being limited in range; in the lower fishes (sharks), intermediate conditions were observed.

Discussion of Dr. Scott's communication brought out the principle that osmotic phenomena had played an important role in evolution, especially of the respiratory organs, circulatory system and skin of vertebrates.

Dr. **Scott's** second paper has been published as pages 1–75 of this volume.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

29 March, 1913

Section was called to order at 8:15 p. m., General James Grant Wilson presiding.

The following programme was offered:

Herbert J. Spinden, Characteristics of Tewa Mythology.
Nels C. Nelson, The Galisteo Pueblos.
Alanson Skinner, Notes on Menomini Folklore.

Summary of Papers

Dr. **Spinden** said in abstract: The myths of the Tewa Indians of the Rio Grande region fall into two groups: (1) cosmogonic and culture hero myths; (2) animal tales, witch stories, etc., of lesser religious significance. The myths have a truly literary quality with many fine touches of human nature and a clear characterization of many individuals, such as certain of the Okhuwa or Cloud People. The myths are closely correlated with the highly specialized religion and are very valuable for the side lights which they throw upon questions of ceremonial usage and ritual. Witch stories are highly developed. Practically no myths from this group of people have hitherto been published.

Mr. **Nelson** read a preliminary account of the past season's archæological work on behalf of the American Museum among the ruined pueblos of the Rio Grande, New Mexico. It was pointed out that the village Indians for centuries were confined to the upper portions of the drainage, owing possibly in part to the lack of water for irrigation in the lower reaches and in part also to the proximity of the marauding Apache. In addition, it was learned from extensive excavations, conducted mainly in the Galisteo Basin country, south of Santa Fé, that a considerable change in the Indian mode of life was effected during the first century of Spanish occupation.

Mr. **Skinner,** in his paper, discussed the cosmological concepts of the Menomini Indians with reference to their bearing on mythology, dwelling on the ritualistic myths of the Medicine Lodge and the manner of their acquisition by candidates. He touched upon the main divisions of Menomini folklore and recounted the taboos and other customs associated with story telling.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

7 April, 1913

The Academy met at 8:17 p. m. at the American Museum of Natural History, President Emerson McMillin presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

Active Membership

Prof. R. A. Harper, Columbia University,
Dr. W. A. Murrill, N. Y. Botanical Garden,
Mr. Norman Taylor, Brooklyn Botanic Garden, Brooklyn,
Mr. W. W. Clendenin, Wadleigh High School.

Associate Membership

Mr. Ralph C. Blanchard, 54 West 40th Street (graduate student, Columbia).

The Recording Secretary then reported the following death:

J. Pierpont Morgan, Active Member of the Academy for 22 years, died 31 March, 1913.

The Academy then adjourned.

E. O. Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

7 April, 1913

Section was called to order at 8:25 p. m., Vice-President J. E. Woodman presiding.

The minutes of the last meeting of the Section were read and approved.

On a reading by Dr. E. O. Hovey, Recording Secretary of the Academy, of the invitation extended the Academy by the Twelfth International Geological Congress, which meets in August, 1913, at Toronto, Canada, the following delegates were nominated by the Section: Dr. J. J. Stevenson, Professor J. Edmund Woodman, Professor James F. Kemp and Professor Charles P. Berkey.

The following programme was then offered:

Raymond Bartlett Earle, The Genesis of Certain Paleozoic Interbedded Iron Ores.

Warren M. Foote, Factors in the Exchange Value of Meteorites. (Read by Title)

Summary of Paper

Mr. **Earle** presented fifty lantern slides, showing both microscopic and gross structures and textures, several being projected by the splendid apparatus of the New York Microscopical Society. About 125 specimens were also exhibited. A further excellent feature was a complete advance summary of the paper, mimeograph copies of which were available for all present.

Mr. Earle's work had been furthered by a grant made by the Academy some months ago. He has visited many exposures along the Paleozoic bedded iron ores in the East, from Tuscaloosa, Alabama, to central New

York, and has compared notes with various mining men and geologists, notably W. C. Phalen, E. C. Eckel, E. F. Burchard, S. W. McCallie, E. A. Smith, D. H. Newland and C. H. Smyth, Jr. He finds that ninety per cent of them agree with Smyth's theory, as modified after James Hall, giving these ores a contemporaneous, sedimentary origin.

Mr. Earle advanced such negative evidences as certain appearances underground which discredit residual origin and an inadequate source of iron according to the older replacement theory. While certain cavernous consolidations containing non-ferruginous sand and some granules coated with calcite argue for replacement, he finds evidence in the impervious strata above and below the somewhat permeable iron formation for a different form of circulation, namely: artesian, for the replacing solutions. He pointed out that not only the Clinton horizon, but various other geologic epochs in the Appalachians carry iron formations of similar origin.

Professor James F. Kemp congratulated the speaker on his excellent presentation of the subject and went on to state rather reasonable sources of iron from iron bi-carbonates carried into estuaries, there deposited as hydrous oxides, later to be hydrated. He inquired as to oxidation at such great depths by artesian waters, as to the sources for the iron and suggested probable stagnation rather than circulation of the waters under the conditions present.

Dr. George F. Kunz suggested present conditions along saline shores, inland seas, and even in extensive bogs of fresh water, any of which might be analogous to conditions during deposition of the Paleozoic ores, and cited the association of the Syracuse salts and Clinton ores.

Professor J. J. Stevenson inquired concerning certain fragments of the ores in the superjacent sediments, cited certain points bearing on leaching and stated that he thinks the whole truth has not been told by the new theory.

The lateness of the hour precluded further discussion.

The Section then adjourned.

Charles T. Kirk,
Secretary.

SECTION OF BIOLOGY

14 April, 1913

Section met at 8:15 p. m., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Roscoe R. Hyde, Fertility and Sterility in *Drosophila.*

Charles Packard, The Effect of Radium on Cellular Activity.

Summary of Papers

Mr. **Hyde** said in abstract: Prolonged and extensive breeding of *Drosophila* has afforded evidence for the view that fertility and sterility are independent hereditary factors which conform to the Mendelian law. Longevity and other physiological characters behave in a similar manner.

The paper was illustrated by a number of charts and diagrams and was discussed by Professor Morgan.

Dr. **Packard's** paper was a conclusion of the communication presented at the previous meeting. It is to be published in the *Journal of Experimental Zoölogy.*

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

21 April, 1913

In accordance with a plan proposed by the Council of the Academy, this meeting of the Section was devoted to a lecture on recent progress in physics and a general reception to the members of the Academy and the Affiliated Societies.

The meeting was opened by Vice-President Charles Lane Poor at 8:15 p. m., about three hundred persons being present, and after a few words explaining the proposed plan of general meetings, the lecture of the evening was presented as follows:

Bergen Davis, Electricity as Revealed by its Passage through Gases.

Summary of Paper

Professor **Davis's** lecture was a summary of recent advances along most interesting lines. It proceeded according to the following synopsis:

Electric phenomena in gases at various pressures;

Discharge with external electrodes and the electrodeless ring discharge;

Electrical nature of matter, cathode rays and the electron;

Mass and electrical charge of the electron;

Positive rays, or so-called canal rays;

Sir Joseph Thomson's experiments with positive rays, the most sensitive method of chemical analysis;

Structure of the atom and possibility of transmutation of elements.

The address was illustrated with many beautiful experiments.

At the termination of the lecture, the Academy held a reception for its friends in the Memorial Hall of the Museum at which a collation was served.

The Section then adjourned.

C. C. Trowbridge,
Secretary pro tem.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

28 April, 1913

The Section met in conjunction with the New York Branch of the American Psychological Association at Columbia University, Professor R. S. Woodworth presiding.

The following programme was offered:

J. McKeen Cattell, Families of American Men of Science.

Clara Jean Weidensall, A Comparison of the Records of the Criminal Woman and the Working Child in a Series of Mental Tests.

A. E. Rejall, The Mentality of Boys in the New York Probationary School—Public School 120—as Determined by the Binet-Simon Test.

George F. Williamson, Some Individual Differences in Immediate Memory Span.

Mabel Barrett, The Order of Merit Method and the Method of Paired Comparisons.

E. K. Strong, Jr., Effect of Size and Frequency on Permanence of Impression.

A. T. Poffenberger, Jr., The Effects of Strychnine on Mental and Motor Efficiency.

Summary of Papers

Professor **Cattell's** paper has been published in full in *Science.*

Mr. **Rejall** said: The New York City Probationary School, formerly Public School 120, located on the "Lower East Side" of Manhattan, became in 1905 a school for the detention and care of incorrigible boys in New York City. Boys attending this school constitute as a class a rough, rebellious, uncontrollable group, and are sent to the school for the following reasons, given in order of their frequency: truancy, insubordination, theft, immorality and violation of the Child Labor Law.

During the period October, 1912, to April, 1913, 103 of the 120 boys which the school normally accommodates were tested by the 1911 Revised Binet-Simon Scale, with the following results: 10 per cent were of normal intelligence, 70 per cent were from one to four years backward, and 20 per cent were distinctly feeble-minded, being from four to six years behind. The average chronological age was thirteen years and ten months, and the average age retardation per pupil was two and one-half years.

These results reinforce the conclusion of others who have used the Binet-Simon Tests on incorrigibles, that mental deficiency is at least an accompaniment and possibly a cause of incorrigibility.

Dr. **Williamson** experimentally tested 31 males and 69 females—in all, 100 subjects. "The 'memory span' is the largest amount of any given material which can always be correctly reproduced immediately after one presentation." [1] The writer has hoped to throw some light on individual and sex differences in immediate memory span.

The materials used were letters (consonants) and figures of one place. The subjects were told what constituted the immediate memory span, and informed that the presentations would be of a gradually expanding series. From time to time, the number of elements in any given "series-presentation" was mentioned by the experimenter. To avoid rhythm, letters and figures were pronounced in a loud tone of voice, to the beats of a metronome—one a second. The subjects listened until the completion of the reading of any *one* series, and then immediately wrote down, in the proper order, what they had heard. Another set was then presented. The test began with a series of six letters, then one of seven was pronounced, one of eight, and finally a series of nine letters. Next another series of six letters was read, then one of seven, one of eight, and again one of nine. Subjects recorded after each "set-presentation." Having completed the eight sets of letters, the eight series of figures were given in exactly the same manner. Credit was given for series correctly reproduced in the proper order. Each individual was credited with the *highest number* of letters or figures that he reproduced correctly every time that many were given him. This was taken as his Immediate Memory Span.

With increase in series length, passing from six-series to nine-series, there is a steady increase in the average number of *mistakes* per individual, and in the average deviation (excepting in the nine-series, where the A.D. is less than in the eight-series). This is practically the case, when (on a per cent basis) we consider the sexes separately. With series

[1] Ladd and Woodworth, "Physiological Psychology," page 574.

of *all* lengths, we have an average number of mistakes for letters of 5.72, with an A.D. of 2.24; while for figures it is only 3.93, but with a greater A.D. of 2.39. When we here consider the sexes separately, we have the same greater number of mistakes for letters, and decidedly greater variability for figures. For both letters and figures, with series of all lengths, there is a grand average number of mistakes of 4.83, with an A.D. of 2.32. From the point of view of the sexes, the same relation holds. However, with all the series, in both letters and figures, the women make more mistakes than the men (av., women, 4.96, men, 4.50). But the men are more variable than the women (A.D., men, 2.41, women, 2.22).

The following table gives the facts for the Immediate Memory Span:

IMMEDIATE MEMORY SPAN—100 SUBJECTS

		Letters		Figures		Grand Av.	
	Mode....	6.0		6.0		6.0	
	Av.	5.69		6.47		6.08	
	A. D.....	0.59		0.92		0.76	
	S. D.	0.73		0.09		0.91	
		Men	Women	Men	Women	Men	Women
On per cent basis.	Mode....	5.0	6.0	7.0	6.0	6.0	6.0
	Av.	5.58	5.74	6.76	6.36	6.17	6.05
	A. D	0.60	0.58	0.89	0.87	0.75	0.73

Using the Pearson coefficient, the writer correlated the memory spans of the 100 subjects and for figures. $r = + .26$ (only), with a P.E. of .06. For the 31 men alone, $r = + .31$, with a P.E. of .10. For the 69 women, $r = + .27$, with a P.E. of .07.

Miss **Barrett** said: In this experiment, the order of merit method and the method of paired comparisons were applied to three series of materials involving judgments of varying subjectivity. The three series consisted of (1) weights, to be judged with respect to their heaviness, (2) specimens of handwriting, to be judged with respect to their excellence, and (3) propositions of varying validity, to be judged with respect to the subject's degree of belief in the fact stated.

The results were used as data by which to compare the relative efficiency of the two methods with regard to statistical investigation of judgment. Seven main problems are suggested, each of which involves a basis of comparison between the two methods.

I. The variability of each specimen in the series from the average position accorded to that specimen, and the consequent average variability of the series. In the case of weights, this average variability is, by the order of merit method, slightly greater than by the paired comparisons method, and in handwriting judgments the exact opposite is true. These averages in isolation might indicate that the one method is particularly favorable to judgment of weight, the other to judgment of handwriting—or the one method to the one group of subjects, and the other method to the other group. These hypotheses are, however, invalidated by the exceedingly high correlation between the two methods for any one type of judgment, and by a comparison of the variabilities in handwriting and beliefs, where the judgments were performed by the same group of subjects. The average of these variabilities for the three types of judgment shows a difference of only .02 between the two methods. The differences in isolated cases may be due to the materials themselves or the groups themselves apart from any consideration of method. They are very evidently *not* due to the *methods*.

II. The second problem is the correlation of the average order with the objective order of the series, by the two methods. In judgment of weights this correlation is exactly the same, and in handwriting *almost* exactly the same for one method as for the other. The difference in the latter case is only .003. In the case of beliefs there is no objective order.

III. The correlation between the arrangements of a given series by the one method and by the other averages .987 for the three types. This indicates that it is unnecessary to employ either one of these methods, which for any reason is less to be preferred, if we consider them with respect to the general results obtained by both.

IV. The individuals of the group correlate as well with their average in the one method as in the other. The differences between the average correlations by the two methods lie in every case within the limits of the probable error.

V. An individual who stands high in correlation with the group arrangement by one method also tends to stand high in that correlation by the other method. This relation is expressed by the correlation + .72 in the case of handwriting and beliefs. In the case of weights, the relation is a random one, + .01. The individual differences in correlation with the average, are, by the paired comparisons method, so insignificant as to make the *order* of correlations subject to chance and very unreliable.

VI. The order of merit method shows a random relation (— .01) between an individual's judgment of handwriting and the same individual's judgment of beliefs. This result accords with the results obtained by other investigations of this sort of problem. In the paired comparisons method this correlation is expressed by — .35. This represents the first and only discrepancy between the equal efficiency of the two methods in this experiment.

VII. A comparison of the groups which performed the one method first with the groups which performed the other method first shows that the method which is employed first does not tend in any way to improve the judgments made by the method which follows it a month later.

On the basis of the efficiency of the two methods for statistical investigation of judgment we may conclude that the one method is in no way to be preferred to the other. From the point of view of convenience, labor, and time required, the order of merit method is by far the more satisfactory of the two.

Mr. **Strong** said, in abstract: In an experiment study continued for some five months considerable information was obtained which throws light upon the statement that in advertising "small spaçe in many media is better than large space in few media." Two points of interest to the psychologist were discussed in the present paper: (1) how does an increase in the size of an advertisement (increase of vividness) affect the permanency of impression made upon the reader? and (2) how does continued repetition of a firm's advertisements affect this permanency of impression?

When the presentations occurred one month apart and the impression was tested one month later by the recognition-test, it was found: (1) that the value of space increases approximately as the square-root of the increase in area, and not directly with the increase in area, and (2) that in this particular case the value of repetition increased exactly as the cube-root of the number of presentations.

Mr. **Poffenberger** said: The investigation was undertaken to determine the effect of ordinary medicinal doses of strychnine on mental and motor processes, and to provide material for a comparative study of the effects of strychnine and caffeine on these processes.

Two subjects were experimented on for a period of thirty days. The test periods were: 9:30 A. M., 1:30, 3:30 and 5:30 P. M.; and for one of the subjects, an additional test at 8:30 P. M. The tests used were as follows: steadiness test, three-hole test, and tapping test, as measures of motor efficiency; and the color-naming test, opposites test, cancellation test, addition test, and multiplication test, as measures of mental efficiency. The motor tests are well known and need no description. The color-naming, opposites, and cancellation tests are described by Woodworth and Wells in their monograph on Association Tests. The addition test required the addition of 17 to each of 50 two-place numbers, and the multiplication test required the multiplication of each of 25 two-place numbers by 7.

The strychnine was given in capsule form, in doses of 1/30 grain during the first week and 1/20 grain during the rest of the period. Each day at 2:45 a capsule was taken, and whether it was a strychnine capsule or only a sugar capsule, the subjects did not know. The schedule was so arranged that in the four weeks about all the combinations of doses were obtained which had been used in the caffeine tests with the 16 subjects. At the end of the four-week period, a two-day intensive study was made, in which tests were begun at 8:30 A. M. and repeated every half hour, until 8:30 P. M. with the exception of two periods for lunch and dinner. In these two days the capsule was taken at 1:45 P. M. A daily introspective report was required from each subject, in which he recorded his physical conditions, etc.

Although the dose was as large as that given in practice, no consistent physical symptoms were noted, such as disturbances of sleep, restlessness, etc., such as were common in the caffeine reports. The curves constructed from the daily tests, and those from the combination of the whole four weeks for separate test periods, show neither an increase in efficiency nor a following period of decreased efficiency, although relapse after stimulation is given as one of the common characteristics of the action of strychnine. The results of the two-day intensive study do not differ from the preceding tests.

There are two possible conclusions to be drawn from the work at this stage. First, the two subjects studied may, by chance, not be susceptible to the action of strychnine except in very large doses. This possibility will be tested by further work with a number of subjects. Secondly, since strychnine acts predominantly on the lower centers of the central nervous system, those in the cord and medulla, the mental processes studied should not be affected. Also, the only effect on motor activity would be a delay of the onset of fatigue by artificially keeping up the tonus of the muscles, a factor which would not enter into the motor tests as they were conducted. The writer inclines to the latter view.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

5 May, 1913

The Academy met at 8:15 P. M. at the American Museum of Natural History, President Emerson McMillin presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

Chester A. Reeds, American Museum of Natural History,
F. F. Hintze, Jr., Columbia University.

ASSOCIATE MEMBERSHIP

Miss May J. Morris, Normal College,
Francis Maurice van Tuyl, Columbia University.

The Secretary reported that Addison Brown, formerly Judge of the United States Court, an Active Member, Fellow and Patron of the New York Academy of Sciences since 1887, died at his residence in New York City on 9 April, 1913, in the eighty-fourth year of his life. His favorite studies were botany and horticulture, but he also took great interest in astronomy. Furthermore, he was a member and benefactor of the New York Botanical Garden, one of its original incorporators, and, at the time of his death, its President.

A Committee, which had been appointed by the Council, consisting of Messrs. N. L. Britton, J. J. Stevenson and E. O. Hovey, then presented a resolution regarding the death of Judge Addison Brown as follows:

Whereas, the Council of the New York Academy of Sciences has learned of the death of Ex-Judge Addison Brown, who for many years has been active in promoting the welfare of botany and its related sciences in this city,

Resolved: That the Council appreciates his service to science and mourns his loss; that this preamble and resolution be entered in the minutes of the Council and a copy be sent to his bereaved family.

The Academy then adjourned.

E. O. HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

5 MAY, 1913

Section was called to order at 8:25 P. M., Vice-President J. E. Woodman presiding.

The minutes of the last meeting of the Section were read and approved.

Following the resignation of Charles T. Kirk as secretary of the Section, Dr. A. B. Pacini was elected to that office.

The first item of the programme of the evening was the discussion of Mr. Earle's paper on the "Genesis of Certain Paleozoic Interbedded Iron Ores," which was presented at the April meeting of the Section.

Professor KEMP opened the discussion by inquiring:

(1) Are there not other oölites than the Clinton which have been replaced?

(2) Would there not be stagnation of water below the vadose region?

Mr. EARLE referred the first question to his colleagues and replied to the second by stating that the impervious strata are not wholly so, but only more so than their contained, loosely aggregated beds. Moreover, he believes, there has been a fluctuation of the ground water level. He thinks also, in reply to Professor Stevenson's inquiry, that the fragments in the superjacent beds are not directly in contact with the iron-formation and cited replacement of pebbles and not of their matrix, as also described in U. S. Geological Survey Bulletin No. 430.

Professor GRABAU then discussed the iron deposits in Tennessee, stating that they are replaced fossils which have not been rolled. He observed that the deposits in Wisconsin have pebbles with surfaces resembling desert varnish and that the pebbles lie at all altitudes. There are no fossils. The beds are lens-shaped. There is apparently wind cross-bedding. There is little cementing silica. He believes that limestone in these instances has been replaced by the iron.

Professor WOODMAN, in describing the iron ores of Nova Scotia, showed that various materials are replaced and that there are isolated granules of iron ore contained in a matrix of mud. He maintains that the cavernous consolidations are unexplained by the syngenetic theory; also that there is either partial replacement or partial leaching in various regions. He finds that the typical examples of replacement are by siliceous and not calcareous materials.

Dr. A. B. PACINI followed with observations on the chemistry of the deposition of iron, showing that as yet too little is known concerning such processes in nature to prophesy certainly as to oxidizing or deoxidizing conditions underground. He referred to Van Bemmelen's results, which show that the yellow oxides of iron deposited chemically are non-colloidal, while the red are colloidal.

Dr. PACINI then gave account of laboratory experiments in passing iron in solution in carbon dioxide through porous calcite and silica at 10 atmospheres pressure. He secures some replacement in a few hours. The experiments are still under way.

The following programme of papers was then offered:

A. W. Grabau, Irrational Stratigraphy: The Right and the Wrong Way of Reconstructing Ancient Continents and Seas.

Ferdinand F. Hintze, Jr., A Contribution to the Geology of the Wasatch Mountains, Utah.

Jesse E. Hyde, Physiographic Studies in the Allegheny Plateau, particularly along its Western Margin in Ohio and Kentucky.

Jesse E. Hyde, A Limestone Dike in Southern Ohio.

Professor **Grabau's** paper on "Irrational Stratigraphy: The Right and Wrong Way of Reconstructing Ancient Continents and Seas" was of the nature of a critique. It was illustrated with paleographic maps by Schuchert, Ulrich, Willis, Chamberlin and Salisbury. The thesis indicated that these maps were too often based on paleontology alone, to the neglect of the sediments themselves, especially their origin. There are sometimes arms of the sea across where the source of a bed of conglomerate would be expected. Erosion was here left out of consideration, and a "stratigraphic hash" was the result. Basins where crinoids, corals, brachiopods, etc., are found are mapped too small.

Questions followed by Professor J. E. Woodman on the width of Appalachia and by Dr. C. A. Reeds on the connection between the Atlantic and Pacific in Silurian time, on the margin of Silurian salts and on the present Atlantic deep where Appalachia was once supposed to be. This last would seem to argue that remarkable sinking has occurred since Paleozoic time.

Professor Grabau thinks that possibly Appalachia did not extend over to the present deep, that is, it was perhaps less than 500 miles wide and may have lain in part where the present Atlantic coastal plain now is. He thinks the Silurian salts may have originated while the Taconic land mass existed to the eastward in such a position as to cut off moisture-bearing winds.

The papers by Messrs. Hintze and Hyde were presented by title.

The Section then adjourned.

Charles T. Kirk,
Secretary.

SECTION OF BIOLOGY

12 May, 1913

Section met at 8:15 P. M., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

J. Gordon Wilson and **F. H. Pike**, A General View of the Function of the Semicircular Canals.

Roy C. Andrews, The California Gray Whale (*Rhachianectes glaucus* Cope): Its History, Habits, Osteology and Systematic Relationship.

Summary of Papers

The paper by Professor **Wilson** and Dr. **Pike**, presented by Dr. Pike, was partly published in the Philosophical Transactions of the Royal Society of London, 1912, Series B, Vol. 203, pp. 127-160. Other papers in press or in preparation.

Mr. **Andrews's** conclusions were as follows: The external and internal anatomy of *Rhachianectes glaucus* present certain characters which seem to demonstrate that this animal is more primitive than any other existing baleen whale. These may be summarized as follows:

1. Long hairs scattered over the entire head and mandible and not confined to certain regions as in other whales.

2. Baleen plates very short, fewer in number and more widely spaced than in other whales.

3. Skull:

a. Exposure of a side strip of the frontals upon the vertex of the skull.

b. Long nasal bones.

c. Comparatively small squamosal having a straight outer edge. This is noticeably different from the concave squamosal of existing baleen whales and is a character of fossil genera.

d. Proximal ends of the premaxillæ very broad, superiorly placed and articulating with the frontals by a deep, interdigitating suture.

e. Orbital processes of the frontals anteriorly overlapped by the edges of the maxillæ, posteriorly with irregular margins and trumpet shaped; all well marked characters of certain fossil baleen whales.

f. A well emphasized temporal ridge.

g. Prominent rugosites upon the supraoccipital, pterygoid and basioccipital bones of the skull.

h. Compressed tympanic bullæ having concave internal borders.

4. Cervical vertebræ entirely free and showing no evidences of ankylosis between members of the series.

5. Atlas and axis possessing massive, rugose neural arches; axis with comparatively small foramina through the wing-like transverse processes.

6. Ribs possessing tubercles, necks and heads as far back as the eighth, and in these portions resembling an Odontocete.

7. A long and straight humerus of the *Plesiocetus* type.

8. Very large pelvic elements, the presence of a large foramen and the comparatively slight reduction of the pubis and ischium.

Relationship of Rhachianectes

Rhachianectes glaucus is apparently not closely related to any of the existing baleen whales, but in some respects it stands intermediate between the Balæninæ and Balænopterinæ, but nearer the latter. In many skull characters, it approaches closely the Pliocene whales of the genus *Plesiocetus* which is allied to the existing Balænopterinæ; in fact, were it not for its specialized mandible, it must certainly be considered as nearly related to them. The fossil whales of the *Plesiocetus* group possessed mandibles having the proximal portion of each ramus, internally, widely concave and leading into a large dental canal; in short, much as in the mandibles of the existing toothed whales. *Rhachianectes,* however, although resembling *Plesiocetus* in many important skull characters, possesses a specialized mandible similar to that of the Right Whales; that is, the proximal portion, internally, is not concave, and the dental canal is small. This type of mandible prevents the phylogenist from taking *Rhachianectes* off from the *Plesiocetus* group, unless he wishes to consider that while persisting until the present day with comparatively little modification of its primitive skull characters, it has undergone considerable specialization of the mandible alone. This is a perfectly possible supposition, which I am inclined to believe is true, since *Rhachianectes* shows such marked affinities to *Plesiocetus* in skull characters and is so strongly separated from the other known genera of fossil and recent whales. It is, upon the whole, one of the most remarkable of existing cetaceans and might be called a "living fossil."

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

29 September, 1913

Section was called to order at 8:15 p. m., Vice-President J. E. Woodman presiding, about 75 members and guests being present.

There being no special business, the following paper was read by title:

Alfred C. Hawkins, The Lockatong Formation of the Triassic of New Jersey and Pennsylvania.

Then the lecture of the evening was presented as follows:

A. Rothpletz, The Simplon Section of the Alps.

Professor Dr. **Rothpletz,** of the University of Munich, after having been introduced and warmly received, proceeded to speak upon his subject without notes, illustrating with diagrams and such slides as could be furnished at short notice by kindness of the authorities of the American Museum of Natural History. At the conclusion of the lecture, Professor James F. Kemp of Columbia University voiced the sentiment of the Section in an appropriate expression of gratitude, alluding incidentally to the fact that Professor Rothpletz was at one time his preceptor.

Summary of Paper

Dr. Charles P. Berkey of Columbia University has kindly prepared the following abstract of Professor Rothpletz's remarks for the Academy's records:

Professor **Rothpletz** explained the different views of the complicated structure of the Alps in the vicinity of the tunnel. Sketches were drawn to illustrate several successive steps or changes of view of the geologists as to the structure of the schistose and gneissic members of the involved series. These were, in part, attempts to explain the seemingly discordant and unexpected data bearing on the distribution of these members as the tunnel work and associated explorations progressed. Most of these sections were after Schmidt, who has worked out the structure in much detail. The slight resemblance of the earlier to the later diagrams was most striking. In all of them, the schists and gneisses were assumed to be definite continuous formations representing dynamically metamorphosed ancient strata, and the structural detail therefore was accredited to folding and related movements.

After a personal study of the ground and special considerations of the petrographic habit of the formations, Professor Rothpletz concluded that the distribution of these gneissic rocks was not primarily dependent upon folding and that their petrographic condition was not wholly due to dynamic metamorphic processes. He suggests that the original strata which formed the basis of the present complications have been extensively affected by igneous intrusions as sills and sheets and by associated influences chiefly in the form of impregnating solutions and magmatic differentiates, producing granitization, which runs in zones or beds or more irregular tongues through or into the strata. If this is the key to the origin of the gneisses, it is evident that much of their tongue-like occurrence and apparent repetition is not due to complicated folding at all, but is essentially a primary structure itself, dependent chiefly on the distribution of weaknesses along which the igneous penetration could take place. This, together with folding of a less complicated sort than had formerly been accredited to the Alps, will, therefore, account for the complex conditions found.

The meeting then adjourned to the Members' room of the Museum, where refreshments were served and an impromptu reception was held, giving the members and friends of the Section an opportunity to meet Professor Rothpletz and to carry away a delightful memory of his genial personality.

The Section then adjourned.

A. B. Pacini,
Secretary.

BUSINESS MEETING

6 October, 1913

The business meeting of the Academy was called to order at 5:45 P. M., at the American Museum of Natural History, by the Recording Secretary. Senior Vice-President Charles Lane Poor then took the Chair. The minutes of the meeting of 5 May were read and approved.

The following candidate for Active Membership in the Academy, recommended by Council, was duly elected:

George I. Finlay, New York University.

The Recording Secretary then reported the following deaths:

James J. Friedrich, Active Member since 1910,

James B. Hammond, Active Member since 1905, died 27 January, 1913, .

Wm. F. Havemeyer, Active Member since 1896, died 7 September, 1913.

Herman Credner, Honorary Member since 1911, died 22 July, 1913,

Frederick A. Ober, Corresponding Member since 1879, died 1 June, 1913.

The Recording Secretary reported from the Council the resignation of Mr. Emerson McMillin as President of the Academy. On motion the Academy adopted the following resolution:

The New York Academy of Sciences, in accepting President McMillin's resignation of his office, expresses its regret that circumstances prevent him from serving to the completion of his term; it would place on record its high appreciation of his devotion to the Academy's interests during the two years in which he has been President.

The Academy then adjourned.

E. O. Hovey,
Recording Secretary.

SECTION OF BIOLOGY

13 October, 1913

Section met at 8:15 P. M., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

W. K. Gregory, H. F. Osborn, A. W. Grabau, W. D. Matthew and R. Broom. Conference on Convergent Evolution, Including a Summary of the Recent Discussion Before the British Association for the Advancement of Science.

Summary of Papers

Dr. **Gregory** spoke under the following headings:

I. Examples and Definitions of Convergence and Parallelism. As an example of convergence, he exhibited the resemblances and differences in the skulls of the "Marsupial Wolf", *Thylacynus,* and the true or Placental Wolf, *Canis lupus.* He discussed the definitions of convergence proposed by Osborn, 1906, Abel, 1911, and Gadow, 1913, accepting Osborn's view that the criterion of absolute *non-homology* between convergent structures was not essential to the conception of convergence. His own definition of convergence was "similar habitus evolved from diverse heritages."

II. Rectigradations (Osborn). These are new characters which appear in earlier phyletic stages as very faint indications, and progressively evolve into useful, functional structures; as the horns of titanotheres, the accessory cusps (*e. g.*, mesostyle, metastylid, etc.) in the molar teeth of Eocene Perissodactyls. These rectigradations appear independently in different families during different stages of evolution. They constitute striking examples of parallelism or convergence in closely related families. Were they due to "a remote hereditary control", *i. e.*, to a delayed manifestation of a hereditary tendency in the generalized ancestral stock (Osborn), or were they merely similar adaptations or responses, appearing in similar materials, subjected to similar stimuli? From his studies on the mechanical interaction of the upper and lower grinding teeth, the speaker concluded that the appearance of new cusps was always conditioned in part by mechanical relations, but he did not take this as a proof of the Lamarckian hypothesis.

III. The matter of rectigradations was intimately connected with Causes of Convergence and Parallelism, a topic forming part of the general problem of reproduction, growth and adaptation in the individual and in the race, and necessitating a brief consideration of Lamarckism versus Natural Selection. From the uniformity of reaction shown in parallelism and convergence, *i. e.*, from the fact that similar adaptations had occurred independently in many groups and at different times, it seemed apparent that somehow the line of progressive adaptation has been determined, in part, by the character of the environment or by the nature of the interaction of one part upon another.

Notwithstanding the case of the blind cave fishes, the Lamarckian hypothesis of the direct transmission of acquired characters was obviously insufficient to explain all cases of progressive adaptation (especially those of the "lock and key" type), and it had been rejected by most authorities. It had, indeed, been shown that in some cases the direct action of the environment upon the soma or body of the parent had modified the germ cells so that the offspring departed from the normal type. Such a sequence may be represented by the symbol $A^a \twoheadrightarrow o \twoheadrightarrow A_1^b$, where A^a represents the parent (A) as modified by the environmental stimulus (a), o represents the germ cells, and A_1^b the modified offspring. Direct transmission of an acquired character might then be represented by the symbol $A^a \twoheadrightarrow o \twoheadrightarrow A_1^a$; but the reality of this sequence is generally denied by experimentalists. The apparent transmission of acquired characters may sometimes have resulted from a sort of convergent evolution between parent and offspring. For example, the extremely long legs of the colt may conceivably be due not to the direct transmission of the effects of exercise from parent to offspring but to the parallel or convergent incidence of selection, operating independently upon both adults and offspring, and thus selecting germ-cells that would give rise both to long-legged colts and to long-legged adults. The opposite case of divergent evolution between parent and offspring (as in larval adaptations) offers grave difficulties to the Lamarckian hypothesis.

Convergence and divergence between juvenile and adult structures are well illustrated in a comparison of the milk and permanent dentitions. In many ungulates, the deciduous grinders evolve into a pattern not like that of the teeth which replace them but like that of the true molars. In the European Badger, on the other hand, the milk teeth are totally unlike the true molars. Where the milk molars are much like the replacing teeth, as in the horse, one might almost suspect a direct transmission of new characters from the earlier to the later dentitions; but this apparent transmission is illusory and so also may be many cases in which juvenile or larval structures resemble those of the parents.

The speaker then referred to a modernized form of the theory of Natural Selection which had been outlined by Professor T. H. Morgan in *Science,*[1] but left the consideration of this topic to subsequent speakers. In conclusion, he said that no matter by what process convergence and parallelism had been effected, the discovery of these phenomena had already had important effects upon our conceptions of classification and phylogeny.

Professor **Osborn** discussed the evolutionary phenomena which have been named by him rectigradations or new structures and allometrons or progressive changes of proportion.

Professor **Grabau,** by means of lantern slides, exhibited convergent evolution in certain phyla of fossil Gastropods, especially among Fusus-like forms.

The substance of Professor **Broom's** remarks were as follows: I think in the present condition of our knowledge that the introduction of a large number of new terms is inadvisable. The three new terms introduced by Gadow, representing three types of convergence, it is impossible accurately to define, and Gadow himself admits that the distinctions are vague. Doubtless the jumping foot of *Macropus* differs in structure from that in *Dipus,* but the force which has produced the specialized foot in the former is doubtless the same as has produced the jumping foot of *Dipus,* the only difference being that Nature had somewhat different material to work on. Gadow gives as an example of "parately" the wings of pterosaurs and of birds. No doubt there is considerable difference both in the appearance and in the intimate structure of those two types of wings, but if we assume, as there is good reason to believe, that the ances-

[1] Science, N. S., Vol. XXXI, 11 Feb., 1910, pp. 201-210.

tral bird had a four-toed wing and, as is quite possible, that this primitive wing was webbed, the only difference of importance between the two types would be the result of different specialization, after convergence had produced similar rudimentary wings, the pterosaur developing the fourth toe and the bird acquiring feathers and the loss of the fourth toe.

I think it better on the whole to keep to the well-known, if slightly indefinite term "convergence" as indicating that type of evolution of which we see so many examples, where from similar or even from very different beginnings Nature evolves structures which closely resemble each other.

It has been said that as a result of convergence, much of our classification is unsatisfactory; that we have grouped together in many cases animals which in appearance resemble one another but have arisen from quite different ancestors. Doubtless there are some cases of the sort, both among mammals and birds, but I am strongly of the opinion that if the complete evolutionary history of every form were known, the changes that would require to be made in our present systems of classification would not be so very great. Such an order as the Insectivora might require to be subdivided into two or more, and the Edentata also probably into three, but it is very unlikely that any change of a serious nature will ever have to be made in such groups as the Marsupials or Monotremes or Primates or Chiroptera or most others. There are always organs little liable to modifications through change of habit, or which at least retain sufficient tell-tale characters, such as the brain, or the organ of Jacobson, or others. Some years ago, I discovered that the Elephant-shrew had an organ of Jacobson quite unlike that of such a typical Insectivore as the Hedgehog, and other researches since have shown good reason why *Macroscelides* and some other forms should be removed from the typical Insectivores to which they have much superficial resemblance. Among the reptiles, probably extremely little modification will have to be made in our classification. Convergence modifies many structures, but there are always more or less conspicuous characters which show the real affinity left if they are but carefully searched for.

It is impossible to discuss convergence without dealing with causes. Dr. Gregory has briefly spoken of the two main theories, Darwinism and Lamarckism, and has given a number of examples which would seem to fit each of those rival theories. Each theory has its advocates, and many of the facts of evolution are quite differently explained by the two. There is at present no complete agreement on the matter, and some of the discussions on the subject show traces of an acrimony that recalls other days. Though in the last twenty years, I have myself published close to a couple of hundred papers dealing with some branch or other of evolution, I have carefully refrained from ever expressing any opinion of the matter of cause. When one's opinions in politics or religion differ from those of the majority, it is often judicious to say nothing about them. Many years ago I came to the conclusion that Darwinism is not the main factor in evolution, and all the work that I have done since has the further confirmed me in this view. I even go so far as to regard it as a secondary factor. That Nature kills off the unfit is of course undeniable, but that this killing off of the unfit brings about the modifications which we see in nature, I do not hold. It is of course easy to give a plausible explanation of how anything may have originated, but I have always looked upon Darwinism as something like the Calvinistic doctrine of foreordination, as one of those things that I could easily prove conclusively, but could never bring myself to believe.

Take, for example, the Australian flying Phalanger (*Petauroides volans*). It is extremely closely allied to the ordinary ring-tailed Phalanger, and were it not for the skin expansion, it would be placed in the same genus (*Pseudochirus*). One might readily argue that a group of ring-tailed Phalangers had a terrible struggle with some carnivorous enemy and that those that were the better able to jump from branch to branch were the ones that escaped, and that gradually through thousands of generations a slight fold in the skin ultimately developed into the large lateral expansion. If we knew nothing of the conditions of life, we would assume that such a struggle was still going on, that all those flying Phalangers that had not their skin fold perfectly developed would be in constant danger of destruction, and that the beautiful mechanism was kept up by the severe struggle for existence. But whatever may have been the conditions in the past, we may safely state that there is no such terrible struggle going on at present. In fact the ring-tailed Phalangers, which have no wing-like expansion, get along just as well as those flying Phalangers which have it. They live in the same trees side by side and presumably have the same enemies, but so far from the ring-tailed Phalanger being handicapped by the absence of the skin expansion, from the fact that it is more common than the flying form we may assume that it gets on at least equally well. From what we know of the animal life during Pleistocene times, we may confidently state that the conditions were closely similar to those we see to-day.

Instances of a like sort might be multiplied indefinitely, and we are almost forced to consider that some other factor has been at work than merely the elimination of the unfit.

Lamarckism affords an explanation of quite a different sort. There seems to be little doubt that when an organ ceases to be of use it becomes rudimentary and disappears, and we might consider it equally probable that when an organ is much used it would increase in development. The ultra-Darwinians hold that even the loss of an organ is the result of natural selection. The reduction in size of the eyes of moles and their elimination is held to be due to the handicapping of those forms with small eyes through ophthalmia and the greater success in the struggle of the forms with eyes too small to become diseased. This explanation might be satisfactory enough to account for the reduction in size of the eye till it ceased to appear on the surface, but it will not account for the still further steady reduction that goes on after the eye is so rudimentary that it is quite below the skin. In *Chrysochloris,* there is a rudimentary but fairly well formed eye far below the surface of the skin. In *Notoryctes,* the reduction has gone to a much further degree, and we find only a trace of the proper eye structure.

Both Darwinism and Lamarckism, while they can furnish us with plausible explanations of increased development, fail to give us any satisfactory explanation of the origin of structures. A tooth cusp we could readily believe might be increased by use, but neither Darwinism nor Lamarckism can give us any explanation of why the cusp first appears. It seems probable, too, that there is some other factor which, while explaining the increase in development of a structure, will also account for its origin.

In the development of mammals, we see many peculiar cases of a parallel evolution. The Eocene types, which are ancestral to the later Ungulates, have small bunodont teeth, and in a large number of different lines of descent these give rise to cusped teeth of a variety of patterns. Various explanations of the phenomenon have been given. It would almost appear as if there were in the early types some latent potentiality and that the long cusped teeth are the manifestation of this inherent possibility. Osborn and others have suggested that the evolution has been controlled by this inherent potentiality of the ancestors, but it seems to me that there is nothing in the evolution of the various mammalian groups that cannot be explained as similar modifications to meet similar conditions. The Eocene and Oligocene mammals were probably the first land forms that became adapted to feeding on grass, and it is probably this diet which has resulted in the peculiar development of the Ungulate molars.

It may be asked if I do not consider that the facts of evolution can be explained by either Darwinism or Lamarckism, to what do I think they are due. I consider that before we can solve this question, we must accumulate a great many more facts, and the field is so vast that there is almost endless work and we will be for years accumulating facts without really requiring a theory of cause at all. Doubtless we cannot go along without at least thinking of causes and certain possibilities suggesting themselves. One of the conclusions to which a palæontologist is almost necessarily driven is that every new modification is a response to some stimulus affecting the part. A new habit alters a limb; a new diet changes a tooth. In each case, the change is such as might be most readily explained by an alteration in the cell activity due to a modification in the nerve control. If we assume, as I believe we must, that acquired characters are inherited, a similar stimulus in succeeding generations would gradually convert the inappreciable alteration in the individual to a manifest distinct specific change in the course of time.

The Section then adjourned.

William K. Gregory,
Secretary.

LECTURE

(In co-operation with the American Museum of Natural History)

27 October, 1913

His Serene Highness, Albert, Prince of Monaco, My Oceanographical Cruises.
(Illustrated with lantern slides.)

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

29 October, 1913

Section met in conjunction with the American Ethnological Society at 8:15 p. m., General James Grant Wilson presiding.

There being no special business to transact, the meeting was devoted to the following lecture:

Robert H. Lowie, Field Notes Among the Hidatsa and Crow Indians.

Summary of Paper

Dr. **Lowie** discussed principally the kinship systems of the Crow and Hidatsa, of which a valuable summary, though incorrect in certain points, is given by Lewis H. Morgan in his "Systems of Consanguinity and Affinity." Morgan notes as peculiarities of the Crow and Hidatsa systems that a mother's brother and an elder brother were addressed by the same term; and that a father's sister's son was addressed as "father", while a father's sister's daughter was addressed as "mother." Dr. Lowie was able to state that the second peculiarity recorded by Morgan is carried out to an even greater extent,—father's sister, father's sister's daughter, father's sister's daughter's daughter, as well as all succeeding female descendants in the female line being included under a common kinship designation. The explanation of this disregard of generations in both of the cases that struck Morgan's attention seems to lie in the influence of the *clan* concept. As there is maternal descent among the Crow and Hidatsa, my mother's elder brother and my own elder brother are both my fellow-clansmen; and as fellow-clansmen are considered brothers, a single kinship term, regardless of age, becomes intelligible. Similarly, my father's sister and all her female descendants through females are members of the same clan as my father. But a father's clansfolk are considered fathers and mothers (or aunts, when not directly addressed) regardless of age; hence it is natural that the term for "father's sister" should include all the female descendants through females of a father's sister. The correctness of this view is corroborated by a test-case. As soon as the clan element is eliminated, a different kinship term must be used. While my father's sister's daughter's daughter is my mother (or aunt), my father's sister's *son's* daughter is not, for she can no longer belong to my father's clan in an exogamous clan system with matrilineal descent.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

3 November, 1913

The Academy met at 5:40 p. m. at the American Museum of Natural History, Vice-President J. E. Woodman presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

Active Membership

George A. Galliver, 60 Broadway,
Freeman F. Burr, 149 Waller Ave., White Plains.

Associate Membership

Miss Laura E. W. Benedict, Columbia University,
F. Berckhemmer, Columbia University.

The Recording Secretary reported the following death:

Mr. Bradley Martin, Active Member since 1905, died 5 February, 1913.

It was voted that a resolution of thanks be sent to Mr. Emerson McMillin for the contribution that had made possible the improvement of the Academy meeting room.

The Academy then adjourned.

E. O. Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

3 November, 1913

Section met at 8:15 p. m., Vice-President J. E. Woodman presiding.

Reading of the minutes of the last meeting of the Section was dispensed with, but the routine business of the Section's November meeting, the nomination of its officers for the ensuing year, was proceeded with. The following nomination was approved for transmission to the Council.

For Vice-President of the Academy and Chairman of the Section: Dr. Charles P. Berkey, Columbia University.

Dr. Albert B. Pacini, 147 Varick St., New York, was elected Secretary for the year 1914.

The following scientific programme was then offered:

Professor Ellsworth Huntington, Changes of Climate During Historical Times.

Summary of Paper

Professor **Huntington,** of Yale University, gave this interesting lecture as a résumé of his studies on climatic conditions in Palestine, Assyria, Turkestan, Egypt and the western United States. An interesting graphic record of yearly rainfall for many centuries, obtained by sectioning the giant redwood trees of the West and noting the comparative thickness of the annual rings, was described. The lecture was profusely illustrated by excellent slides and was warmly received and applauded.

After the lecture, a collation was served in the Eskimo Hall. A reception to Professor Huntington ended a pleasant evening, and the Section then adjourned.

Albert B. Pacini,
Secretary.

SECTION OF BIOLOGY

10 November, 1913

Section met at 8:15 p. m., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

The following nomination of officer for the year 1914 was made and approved for transmission to the Council:

For Vice-President of the Academy and Chairman of the Section: Professor Raymond C. Osburn.

Dr. William K. Gregory was elected Secretary for the year 1914.

The Secretary read a letter from the Recording Secretary, stating that the Council had voted to assign to any section requesting it, a certain volume of the Annals, to contain papers emanating from the members of that section, the control of publication, however, remaining as heretofore with the Council.

It was moved and seconded that a committee be appointed by the Chairman to consider the publication of a separate volume of the Annals to contain papers read at the meetings of the section. Motion carried. The Chairman stated that he would appoint such a committee.

It was moved and seconded that the next meeting of the section, on 8 December, 1913, should be devoted to a conference on Unit Characters.

By request of the Secretary, it was voted that a Committee on Arrangements should be appointed by the Chairman to assist the officers of the Section in carrying on the work of the Section and in extending its membership.

The following lecture was then offered:

Dr. Robert Broom, The Origin of Mammals.

Summary of Paper

Dr. **Broom,** formerly Professor of Geology and Zoölogy in Victoria College, Stellenbosch, South Africa, illustrated his lecture with lantern slides, and especially with a series of South African mammal-like reptiles, and said in abstract: In 1876, Owen, in describing the fossil reptiles of

South Africa, pointed out numerous mammal-like characters seen in them and in 1880 definitely expressed the view that the primitive mammals living to-day in Australia are the direct descendants of a reptilian ancestor such as he had described. Huxley, on the other hand, favored the descent of the mammals from a salamander-like form, and the contest between those who believe they are descended from amphibians and those who look on reptiles as their ancestors has been urged ever since—sometimes rather vigorously.

When Cope, in 1880, studied the remarkable pelycosaurs, fin-backed reptiles found in the old Permian rocks of New Mexico and Texas, he came to the conclusion that he had found, if not the mammalian ancestors, at least forms allied to them, and in this I believe he was quite correct.

Between 1888 and 1905, Professor Osborn published a considerable number of papers dealing with the origin of mammals, in which he argued that the ancestor of the mammal was probably a member of that group of very mammal-like reptiles found in South Africa and called Cynodonts. This view of Osborn's seems at first sight opposed to that of Cope's, but in all probability both views were correct, the Pelycosaurs being a side branch from a direct line very near to the early mammalian ancestors, the Cynodonts being probably the immediate ancestors of the mammal.

Baur, who worked here in America and died some fifteen years ago, was in favor of the reptile origin. Seeley adopted a rather curious view. He believed that the egg-laying mammals came from reptiles but that other mammals arose from amphibians. On the whole, the Germans have favored the amphibians as ancestors, while English opinion, although somewhat divided, has mainly been in support of the reptilian theory. The majority of Americans, doubtless influenced by Cope and Osborn, have always favored the descent of the mammals from a reptilian ancestor.

I became interested in the question in 1885 and practically resolved then that I would contribute what I could to the solution of the problem. In 1892, I went to Australia and spent some years in studying the egg-laying mammals and marsupials. In 1897, I went to South Africa and have been working in that region for the last seventeen years. In these seventeen years, nearly every specimen that has been picked up there has passed through my hands.

After describing the Karroo formation in which these fossils are found, the speaker described some of the principal types of mammal-like reptiles as follows: The oldest animals we meet with in the Karroo formation in any number are of middle Permian age, shall we say of the year 18,000,000 B. C. These are of especial interest from the resemblance they bear to the American Permian reptiles from Texas and New Mexico. One of the largest and best-known animals is called *Pareiasaurus.* It is a large-limbed reptile, about nine feet in length and standing about three and one-half feet in height. In many points of its organization it shows affinities with the American reptile *Diadectes,* of which a mounted skeleton is to be seen in the American Museum. Another group of animals contemporaneous with *Pareiasaurus* is the reptilian group of Dinocephalians. These also were large reptiles with very powerful limbs. Although herbivorous and having no remarkable specialization of the spines of the vertebræ, they are nevertheless fairly closely allied to the very remarkable American fin-backed Pelycosaurs, of which skeletons are to be seen in the American Museum.

One of the most striking peculiarities of the Karroo reptiles is that almost all agree with *Pareiasaurus* and the Dinocephalians in having powerfully developed limbs. How these have been evolved is a matter of doubt, but there can be little question that it was this strengthening and lengthening of the limbs that started the evolution which ultimately resulted in the formation of the warm-blooded mammals.

The best-known, and in some respects the most remarkable, of the Karroo reptiles belong to a group named by Owen the Anomodonts, from their having horny beaks like the turtles or birds with, in addition in many forms, a pair of large walrus-like tusks. The first specimen was discovered as far back as 1844 and was called *Dicynodon,* but, although many skulls have been discovered, only three or four fairly good skeletons have been found. In limbs, shoulder and pelvic girdles and essential structure of the skull and in the number of joints of the toes, they strikingly resemble the mammals, and although the curious development of the beak obscures the mammal-like character of the skull, it is essentially built on the mammalian plan, and there is little doubt that although the Anomodonts are a side offshoot from the mammalian stem, they are closely allied to the mammalian ancestor.

A form nearly allied to *Dicynodon* is called *Endothiodon.* It has no large tusk but a number of small teeth. Although much rarer than *Dicynodon,* fortunately an almost complete skeleton has been discovered, which has recently been mounted in the Museum laboratories by Mr. Charles Falkenbach under my direction, and of which a photograph is given. The extremely mammal-like condition of the limbs is very manifest, and there is little doubt that the animal waddled about somewhat after the manner of the pigmy hippopotami of Liberia, seen at the New York Zoölogical Park. Attention may be called to the relatively enormous size of the skull and the curious way in which the long point of the lower jaw passes up into the groove in the upper.

We find many other mammal-like reptiles of which the Therocephalians, Dromasaurians and the Cynodonts are the most important. Although these insectivorous and carnivorous types are less mammal-like in some respects than the Anomodonts, they agree more closely with the mammals in the construction of the skull. They all have long, slender limbs adapted for running. The earlier members, such as the lower Therocephalians, have the number of toe joints as still found in the lizards and most reptiles, viz., 2, 3, 4, 5, 3; but the Anomodonts, the lower Dromasaurians and the higher Cynodonts have the same number of joints in the toes as is retained in ourselves, 2, 3, 3, 3, 3. It is rather interesting to look at one's hand and realize that the fingers have all these joints because a remote ancestor took to walking with the feet under the body, supporting it off the ground, rather than with the feet to the side as in the lizards and crocodiles.

The Cynodonts occur in the Triassic formation and a few survive into the Jurassic. In most points of structure, they are extremely mammal-like and it is frequently impossible, if the specimen is at all incomplete, to say whether we are dealing with one of the Cynodonts or a mammal. The lower jaw is almost entirely formed by a large single bone, the posterior bones being small, and the bone on which the jaw hinges is also small, thus foreshadowing the mammalian condition, the dentary bone, the angular, articular and surangular being quite small, as is also the quadrate bone. The teeth are in most forms of a carnivorous type, composed of sharp incisors, long sharp canines and cusped molars, the cusps being almost exactly like those of the carnivorous mammals.

A couple of months ago, I discovered that in the Cynodonts, the incisors, canines and premolars are preceded by an earlier set exactly as in ourselves. It would probably be inappropriate to call them milk teeth, as it is very unlikely that the Cynodonts provided their young with milk, but there can be no doubt that the young had a first temporary set of front teeth like most mammals.

Besides solving the question of the origin of the mammals, the Karroo fossil beds have thrown some light on the origin of birds. There has been considerable discussion as to whether birds were derived from flying bat-like reptiles called pterodactyls or from the dinosaurs. Some have even gone so far as to derive the flying birds from the pterodactyls and the running birds such as the ostrich from the dinosaurs. Dr. Lucas is one of those who favors a double origin for the birds. Professor Osborn some years ago argued in favor of the birds and dinosaurs having come from a common ancestor in Permian times. A few years ago I maintained, as the result of my studies on the development of the ostrich, that the ancestor of the bird though not a dinosaur was nearly a dinosaur, and that the bird and the carnivorous dinosaur were derived from a group of primitive dinosaur-like reptiles that were capable of running on their hind legs. A recent discovery in South Africa reveals just such a type as we required for the common ancestry of the birds and the dinosaurs, and this form is also not far removed from the ancestor of the pterodactyl. The birds, pterodactyls and carnivorous dinosaurs are all probably sprung from a small reptile such as the one recently discovered in South Africa and named by me *Euparkeria.*

Another interesting fact that seems to be brought out by our study of the South African fossil forms is that it was probably the development of the active Cynodonts that led to the development of the active reptiles such as *Euparkeria.* For possibly two million years, the carnivorous mammal-like reptiles had an abundant supply of food in the form of the small Anomodonts. In lower Triassic times, the smaller Anomodonts seem to have become extinct for some reason, and the carnivorous forms had to obtain a new diet, which was probably a little lizard-like animal called *Procolophon*, and possibly other small reptiles of a similar type. It was possibly this new activity that gave rise to the Cynodonts. In upper Triassic times, the Procolophons became extinct, and the small Cynodonts were driven to attacking the more active types like *Euparkeria.* The rivalry between these forms resulted in the greatly increased activity of both, the active four-footed forms becoming the primitive mammals and those which run on their hind legs gave rise to the theropodus dinosaurs and the ancestral birds. The further evolution of the bird was doubtless the result of its taking to an arboreal habit and developing feathers.

A fuller report of Dr. Broom's lecture is printed in the "American Museum Journal," December, 1913.

Professor Osborn spoke of the commanding importance of Dr. Broom's researches and discoveries and moved that the Secretary should be instructed to record on the minutes a cordial vote of thanks to Dr. Broom. The motion was unanimously carried.

The lecture was followed by a reception to Dr. Broom.

The Section then adjourned.

William K. Gregory,
Secretary.

LECTURE

17 November, 1913

Carl Skottsberg, The Vegetation of Patagonia, Fuegia and the Subantarctic Islands.

(Illustrated with lantern slides.)

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

24 November, 1913

Section met in conjunction with the New York Branch of the American Psychological Association at 8:00 p. m. The meeting was held in the Psychological Laboratory of Columbia University, Professor R. S. Woodworth presiding.

The following nomination of officer for the year 1914 was made and approved for transmission to the Council:

For Vice-President of the Academy and Chairman of the Section: Dr. Clark Wissler.

Dr. Robert H. Lowie was elected Secretary for the year 1914.

The following programme was offered:

Richard H. Paynter,	Measurements of Accuracy of Judgment.
W. P. Montague,	Prof. Thorndike's Attack on the Ideo-motor Theory.
J. P. Turner,	The Character of Ideas.
Mrs. Christine Ladd Franklin,	The Color Vision of Animals.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

1 December, 1913

The Academy met at 8:25 p. m. at the American Museum of Natural History, Vice-President J. E. Woodman presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

Active Membership

George S. Huntington, College of Physicians and Surgeons,
Frank G. Haughwout, 316 West 79th Street,
Harry R. Salomon, 258 Riverside Drive.

Associate Membership

Waldo Shumway, Columbia University,
L. A. Adams, Columbia University,
H. E. Anthony, American Museum of Natural History,
F. K. Morris, 485 Central Park West.

The Recording Secretary then reported the following deaths:

Frederick Billings, Active Member since 1910, died 5 May, 1913,
George B. Post, Active Member since 1895, died 28 November, 1913.

The Academy then adjourned.

E. O. Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

1 December, 1913

Section met at 8:15 p. m., Vice-President J. E. Woodman presiding.

The minutes of the two preceding meetings were read and approved.

A communication from Dr. E. O. Hovey, Recording Secretary of the Academy, was read, informing the Section of the Council's vote to reserve a certain volume of the Annals to a section requesting it, to contain papers emanating from the members of that section. After some discussion, no decision was arrived at upon this matter.

Professor J. F. Kemp exhibited a specimen of cedar tree found in glacial drift one foot from bedrock, 81 feet below curb, on the site of the Equitable Life Insurance Building, at Broadway, Cedar, Pine and Nassau streets, courtesy of J. R. Kilpatrick of the Thompson-Starrett Co.

The following programme was then offered:

Miss Marjorie O'Connell, A Revision of the Genus Zaphrentis (Read by Title).
Francis M. Van Tuyl, The Origin of Geodes.
Charles P. Berkey, Origin of Some of the Complex Structures of the Ancient Gneisses of New York.

Charles Reinhard Fettke, The Manhattan Schist of Southeastern New York State and its Associated Igneous Rocks.

Summary of Papers

Mr. **Van Tuyl** made especial reference to the geode-bearing beds of Iowa, Missouri and Illinois, and presented the theory that geodes originated in cavities left by the solution of concretions in these beds, these cavities being filled by crystallization from mineralizing solutions penetrating them, these solutions having their dissolved content replaced by osmosis as it was depleted by deposition.

The paper was discussed by Mr. Levison, Dr. Hovey and Professor Grabau.

Dr. **Berkey's** paper was read by Mr. G. S. Kearney, owing to Dr. Berkey's absence because of illness. In this section of the paper Dr. Berkey treated the origin of streaked and foliated structures which he insisted was due primarily to regional disturbance and which led him to regard Yonkers gneiss as essentially primary.

A few remarks of approbation were made by Professor Grabau.

Professor James F. Kemp gave a brief summary of a paper entitled "The Manhattan Schist of Southeastern New York State and its Associated Igneous Rocks," by Charles Reinhard Fettke.

After a collation, the Section adjourned.

Albert B. Pacini,
Secretary.

SECTION OF BIOLOGY

8 December, 1913

Section met at 8:15 p. m., Vice-President W. D. Matthew presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Henry Fairfield Osborn, Unit Characters in Heredity as They Appear to the Paleontologist.

Summary of Paper

Professor **Osborn's** paper will be published in the U. S. Geological Survey Monograph on Titanotheres.

The paper was discussed by Professors T. H. MORGAN, C. B. DAVENPORT and R. BROOM.

WILLIAM K. GREGORY,
Secretary.

ANNUAL MEETING

15 DECEMBER, 1913

The Academy met in Annual Meeting on Monday, 15 December, 1913, at the Hotel Endicott, at the close of the annual dinner, Senior Vice-President Charles Lane Poor presiding.

The minutes of the last Annual Meeting, 15 December, 1912, were read and approved.

Reports were presented by the Corresponding Secretary, the Recording Secretary, the Librarian and the Editor, all of which, on motion, were ordered received and placed on file. They are published herewith.

The Treasurer's report showed a net cash balance of $2,821.67 on hand at the close of business, 30 November, 1912. On motion, this report was received and referred to the Finance Committee for auditing.

The following candidates for honorary membership and fellowship, recommended by the Council, were duly elected:

HONORARY MEMBERS

Prof. Charles Déperet, Lyons, France, presented by Prof. James F. Kemp.

Sir David Prain, Director, Royal Botanical Garden, Kew, England, presented by Prof. Nathaniel Lord Britton.

FELLOWS

Oakes Ames, North Easton, Mass.,
Prof. Robert A. Harper, Columbia University,
Prof. William Mansfield, 115 West 68th Street,
Dr. William A. Murrill, New York Botanical Garden,
Dr. Chester A. Reeds, American Museum of Natural History,
Dr. George G. Scott, College of the City of New York,
Charles E. Sleight, Ramsay, N. J.,
Norman Taylor, Brooklyn Botanic Garden, Brooklyn.

The Academy then proceeded to the election of officers for the year 1914. The ballots prepared by the Council in accordance with the By-laws were distributed. On motion, it was unanimously voted that the Recording Secretary cast one affirmative ballot for the entire list nominated by the Council. This was done and they were declared elected, more than the requisite number of members and Fellows entitled to vote being present:

President, George F. Kunz.

Vice-Presidents, Charles P. Berkey (Section of Geology and Mineralogy), Raymond C. Osburn (Section of Biology), Charles Baskerville (Section of Astronomy, Physics and Chemistry), Clark Wissler (Section of Anthropology and Psychology).

Corresponding Secretary, Henry E. Crampton.

Recording Secretary, Edmund Otis Hovey.

Treasurer, Henry L. Doherty.

Librarian, Ralph W. Tower.

Editor, Edmund Otis Hovey.

Councilors (to serve 3 years), Wallace Goold Levison, Marshall A. Howe.

Finance Committee, Emerson McMillin, Frederic S. Lee, John Tatlock.

At the close of the elections, the following illustrated lecture was given:

Dr. Daniel Trembly MacDougal, The Sudan and Libyan Deserts.

Dr. **MacDougal** related experiences and observations on a botanical reconnoissance undertaken in connection with the research work of the Carnegie Institution of Washington.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

REPORT OF THE CORRESPONDING SECRETARY

We have lost by death during the past year the following Honorary Member:

Hermann Credner, elected 1911, died 22 July, 1913,

and the following Corresponding Member:

Frederick A. Ober, elected 1879, died 1 June, 1913.

There are at present upon our rolls 48 Honorary Members and 122 Corresponding Members.

Respectfully submitted,

Henry E. Crampton,
Corresponding Secretary.

REPORT OF THE RECORDING SECRETARY

During the year 1913, the Academy held 9 business meetings and 20 sectional meetings, at which 58 stated papers were presented as follows:

Section of Geology and Mineralogy, 13 papers; Section of Biology, 19 papers; Section of Anthropology and Psychology, 26 papers.

Two of the sectional meetings were of general character and of particular interest and were followed by a social hour, with refreshments, in one of the exhibition halls of the Museum. They were attended by from two hundred to three hundred members and their friends, who seemed to enjoy this innovation in the Academy meetings.

The first was held under the auspices of the Section of Astronomy, Physics and Chemistry on the evening of 21 April, when Professor Bergen Davis, of Columbia University, gave a lecture upon "Electricity as Revealed by its Passage Through Gases." The other was held on 3 November under the auspices of the Section of Geology and Mineralogy, when Professor Ellsworth Huntington, of Yale University, lectured upon "Changes of Climate During Historical Times."

In addition to these general meetings of the Academy, three public lectures were given to the members of the Academy and the Affiliated Societies and their friends, as follows:

"The Simplon Section of the Alps." By Dr. A. Rothpletz, Professor of Geology in the University of Munich.

"My Oceanographical Cruises." By His Serene Highness, Albert, Prince of Monaco.

"The Vegetation of Patagonia, Fuegia and the Subantarctic Islands." By Dr. Carl Skottsberg, Professor of Botany in the University at Upsala, Sweden.

Two special meetings of the Council and some of the Fellows actively engaged in scientific work in the city were held during the year to formulate plans for carrying out some of the suggestions made in President McMillin's address a year ago. The first was held on 28 February, at the Hotel Ansonia, where those present were the guests of President Emerson McMillin, and the second was held on 24 March, at Delmonico's, where Treasurer Henry L. Doherty was the host. As an outcome of these meetings, a special committee on the extension of the Academy's work was formed and plans were adopted for work which the Academy hopes to begin next year.

At the present time, the membership of the Academy is 481, which includes 462[1] Active Members (of whom 28 are Associate Members, 88 Fel-

[1] Including eight members elect who have not yet paid their first annual dues.

lows, 93 Life Members and 9 Patrons) and 19 Non-resident Members. There have been 14 deaths during the year, 15 resignations have become effective and 1 name has been dropped from the roll for non-payment of dues. Twenty-one new members have been elected during the year, and two names have been restored to the life-membership list. As the membership of the Academy a year ago was 488, there has been a net loss of 7 during the year 1913. Record is made with regret of the loss by death of the following members:

Addison Brown, Active Member and Patron since 1887.
Frederick Billings, Active Member since 1910.
James J. Friedrich, Active Member since 1910.
Albert C. Goodwin, Active Member since 1910.
James B. Hammond, Active Member since 1905.
William F. Havemeyer, Active Member since 1896.
John B. Marcou, Active Member since 1906.
Bradley Martin, Active Member since 1905.
Walter H. Mead, Active Member since 1882 (Patron since 1888).
J. Pierpont Morgan, Active Member since 1891.
Eugene H. Paddock, Active Member since 1907.
John R. Planten, Active Member since 1907.
George B. Post, Active Member since 1895.
George S. Scott, Active Member since 1907.

Respectfully submitted,

EDMUND OTIS HOVEY,
Recording Secretary.

REPORT OF THE LIBRARIAN

The Library of the New York Academy of Sciences has received during the current year by exchange and donation 262 volumes and 1,913 numbers. Persistent efforts have again been made to complete the imperfect files of serial publications which still exist on our shelves, but with the exception of five volumes received from the Société de L'Industrie Minérale to whom special acknowledgments are herewith extended, the results have been few.

It is a pleasure, however, to report that the Library formed in part by the collection belonging to the New York Academy of Sciences is being extensively used by neighboring institutions as well as by scientists from many states.

Respectfully submitted,

RALPH W. TOWER,
Librarian.

REPORT OF THE EDITOR

The parts of the Annals which have been published this year are the following:

VOLUME XXII

	Pages
E. O. Hovey—Records of Meetings of the Academy	339–388
Charter and Constitution of the Academy	389–394
Constitution and By-laws	395–402
Membership of the Academy	403–414
Index	415–423

VOLUME XXIII

G. G. Scott—A Physiological Study of the Changes in *Mustelus canis*, produced by modifications in the Molecular Concentration of the External Medium	1–75
William Morton Wheeler—Corrections and Additions to my "List of Type Species of the Genera and Subgenera of Formicidæ"	77–84
Ferdinand F. Hintze, Jr.—A Contribution to the Geology of the Wasatch Mountains, Utah	85–143

There is likewise in press a paper by A. C. Hawkins entitled "Contribution to the Geology of the Lockatong Formation," and the Publication Committee has accepted three other papers for publication in the Annals—one by Miss Marjorie O'Connell, "Revision of the Genus Zaphrentis," one by Charles R. Fettke, "The Manhattan Schist of Southeastern New York and its Associated Igneous Rocks," and one by Miss Laura W. Benedict, "A Study of Bagobo Ceremonial, Magic and Myth." The last is to form the first part of Volume 25 of the Annals, which is to be devoted exclusively to anthropological papers in accordance with a recent vote of the Council.

Respectfully submitted, EDMUND OTIS HOVEY,

Editor.

REPORT OF THE TREASURER

MEMBERSHIP

Paid up, Active Members (4 of these were elected after 1 May and paid $5 for 1913)	301
Paid up, Associate Members	22
Delinquent Active and Associate Members	33
Life Members and Patrons	102
	458[1]

[1] Including four deceased members whose dues have been paid to the end of the year.

RECEIPTS

DECEMBER 1, 1912—NOVEMBER 30, 1913

Cash on hand, December 1, 1912		$1,555.51
Life membership fee		100.00
Income from investments:		
Interest on mortgages on New York City real estate	$860.00	
Interest on railroad and other bonds	1,457.00	
		2,335.00
Interest on bank balances		41.37
Active membership dues, 1910	20.00	
" " " 1911	50.00	
" " " 1912	145.00	
" " " 1913	2,990.00	
" " " 1914	5.00	
		3,210.00
Associate membership dues, 1911	3.00	
" " " 1912	12.00	
" " " 1913	66.00	
		81.00
Sales of publications		103.65
Subscriptions to annual dinner		144.00
Redemption of 5 Canada Southern Railway Company's bonds		5,000.00
Total		$12,570.53

DISBURSEMENTS

DECEMBER 1, 1912—NOVEMBER 30, 1913

Publication on account of Annals	$901.48
Publication of *Bulletin*	569.23
Recording Secretary's expenses	311.07
Recording Secretary's and Editor's allowances	1,400.00
Lecture Committee	175.00
General expenses	145.50
Esther Herrman Research Fund (grants)	260.00
John Strong Newberry Fund (grants)	200.00
Annual meeting and dinner	149.98
Purchase of U. S. Steel Corporation bonds	5,081.25
Interest charge on bond purchased	55.55
General meetings	339.70
Section of Geology and Mineralogy	85.00
Section of Anthropology and Psychology	75.00
Collection charge on check	.10
Cash on hand	2,821.67
Total	$12,570.53

BALANCE SHEET, NOVEMBER 30, 1913

Investments (cost)	$42,526.25	Permanent Fund	$22,912.57
Cash on hand.............	2,821.67	Publication Fund	3,000.00
		Audubon Fund	2,500.00
		Esther Herrman Research Fund	10,000.00
		John Strong Newberry Fund	1,000.00
		Income Permanent Fund..	3,470.06
		Income Audubon Fund....	459.83
		Income Esther Herrman Fund	1,706.27
		Income Newberry Fund...	299.19
	$45,347.92		$45,347.92

PROPERTY

			Cost
Lampe Mortgage.................................	at 5	per cent..	$12,000.00
Deane-Brennan Mortgage.........................	at 5½	per cent..	5,200.00
4 Detroit City Gas Company's bonds...............	at 5	per cent..	4,000.00
3 Grand Rapids Gas Light Company's bonds.......	at 5	per cent..	2,910.00
10 Madison Gas and Electric Company's bonds.....	at 6	per cent..	10,400.00
1 Binghamton Gas and Electric Company's bond...	at 5	per cent..	995.00
1 Quebec-Jacques Cartier Electric Company's bond..	at 5	per cent..	965.00
1 Southern Light and Traction Company's bond....	at 5	per cent..	975.00
5 U. S. Steel Corporation bonds..................	at 5	per cent..	5,081.25
			$42,526.25

HENRY L. DOHERTY,
Treasurer.

17 JANUARY, 1914.

Examined and found to be correct,

FREDERIC S. LEE,
JOHN TATLOCK,
Auditing Committee.

THE ORGANIZATION OF THE NEW YORK ACADEMY OF SCIENCES

THE ORIGINAL CHARTER

AN ACT TO INCORPORATE THE

LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK

Passed April 20, 1818

WHEREAS, The members of the Lyceum of Natural History have petitioned for an act of incorporation, and the Legislature, impressed with the importance of the study of Natural History, as connected with the wants, the comforts and the happiness of mankind, and conceiving it their duty to encourage all laudable attempts to promote the progress of science in this State—therefore,

1. *Be it enacted by the People of the State of New York represented in Senate and Assembly,* That Samuel L. Mitchill, Casper W. Eddy, Frederick C. Schaeffer, Nathaniel Paulding, William Cooper, Benjamin P. Kissam, John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements and James Pierce, and such other persons as now are, and may from time to time become members, shall be, and hereby are constituted a body corporate and politic, by the name of LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK, and that by that name they shall have perpetual succession, and shall be persons capable of suing and being sued, pleaded and being impleaded, answering and being answered unto, defending and being defended, in all courts and places whatsoever; and may have a common seal, with power to alter the same from time to time; and shall be capable of purchasing, taking, holding, and enjoying to them and their successors, any real estate in fee simple or otherwise, and any goods, chattels, and personal estate, and of selling, leasing, or otherwise disposing of said real or personal estate, or any part thereof, at their will and pleasure: *Provided always,* that the clear annual value or income of such real or personal estate shall not exceed the sum of five thousand dollars: *Provided,* however, that the funds of the said Corporation shall be used and appropriated to the promotion of the objects stated in the preamble to this act, and those only.

2. *And be it further enacted,* That the said Society shall from time to time, forever hereafter, have power to make, constitute, ordain, and establish such by-laws and regulations as they shall judge proper, for the elec-

tion of their officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of the officers and members thereof; for collecting annual contributions from the members towards the funds thereof; for regulating the times and places of meeting of the said Society; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for the managing or directing the affairs and concerns of the said Society: *Provided* such by-laws and regulations be not repugnant to the Constitution and laws of this State or of the United States.

3. *And be it further enacted,* That the officers of the said Society shall consist of a President and two Vice-Presidents, a Corresponding Secretary, a Recording Secretary, a Treasurer, and five Curators, and such other officers as the Society may judge necessary; who shall be annually chosen, and who shall continue in office for one year, or until others be elected in their stead; that if the annual election shall not be held at any of the days for that purpose appointed, it shall be lawful to make such election at any other day; and that five members of the said Society, assembling at the place and time designated for that purpose by any by-law or regulation of the Society, shall constitute a legal meeting thereof.

4. *And be it further enacted,* That Samuel L. Mitchill shall be the President; Casper W. Eddy the First Vice-President; Frederick C. Schaeffer the Second Vice-President; Nathaniel Paulding, Corresponding Secretary; William Cooper, Recording Secretary; Benjamin P. Kissam, Treasurer, and John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements, and James Pierce, Curators; severally to be the first officers of the said Corporation, who shall hold their respective offices until the twenty-third day of February next, and until others shall be chosen in their places.

5. *And be it further enacted,* That the present Constitution of the said Association shall, after passing of this Act, continue to be the Constitution thereof; and that no alteration shall be made therein, unless by a vote to that effect of three-fourths of the resident members, and upon the request in writing of one-third of such resident members, and submitted at least one month before any vote shall be taken thereupon.

State of New York, Secretary's Office.

I CERTIFY the preceding to be a true copy of an original Act of the Legislature of this State, on file in this Office.

ARCH'D CAMPBELL,

ALBANY, *April* 29, 1818. *Dep. Sec'y.*

ORDER OF COURT

ORDER OF THE SUPREME COURT OF THE STATE OF NEW YORK TO CHANGE THE NAME OF

THE LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK

TO

THE NEW YORK ACADEMY OF SCIENCES

WHEREAS, in pursuance of the vote and proceedings of this Corporation to change the corporate name thereof from "The Lyceum of Natural History in the City of New York" to "The New York Academy of Sciences," which vote and proceedings appear to record, an application has been made in behalf of said Corporation to the Supreme Court of the State of New York to legalize and authorize such change, according to the statute in such case provided, by Chittenden & Hubbard, acting as the attorneys of the Corporation, and the said Supreme Court, on the 5th day of January, 1876, made the following order upon such application in the premises, viz:

At a special term of the Supreme Court of the State of New York, held at the Chambers thereof, in the County Court House, in the City of New York, the 5th day of January, 1876:

Present—HON. GEO. C. BARRETT, *Justice.*

In the matter of the application of the Lyceum of Natural History in the City of New York to authorize it to assume the corporate name of the New York Academy of Sciences.

On reading and filing the petition of the Lyceum of Natural History in the City of New York, duly verified by John S. Newberry, the President and chief officer of said Corporation, to authorize it to assume the corporate name of the New York Academy of Sciences, duly setting forth the grounds of said application, and on reading and filing the affidavit of Geo. W. Quackenbush, showing that notice of such application had been duly published for six weeks in the State paper, to wit, *The Albany Evening Journal,* and the affidavit of David S. Owen, showing that notice of such application has also been duly published in the proper newspaper of the County of New York, in which county said Corporation had its business office, to wit, in *The Daily Register,* by which it appears to my satisfaction that such notice has been so published, and on reading and filing the affidavits of Robert H. Browne and J. S. Newberry, thereunto annexed, by which it appears to my satisfaction that the application is made in pursuance of a resolution of the managers of said Corporation to that end named, and there appearing to me to be no reasonable objection to said Corporation so changing its name as prayed in said petition: Now on motion of Grosvenor S. Hubbard, of Counsel for Petitioner, it is

Ordered, That the Lyceum of Natural History in the City of New York be and is hereby authorized to assume the corporate name of The New York Academy of Sciences.

Indorsed: Filed January 5, 1876,

A copy. WM. WALSH, *Clerk.*

Resolution of THE ACADEMY, *accepting the order of the Court, passed February 21, 1876*

And whereas, The order hath been published as therein required, and all the proceedings necessary to carry out the same have been had, Therefore:

Resolved, That the foregoing order be and the same is hereby accepted and adopted by this Corporation, and that in conformity therewith the corporate name thereof, from and after the adoption of the vote and resolution herein above referred to, be and the same is hereby declared to be THE NEW YORK ACADEMY OF SCIENCES.

AMENDED CHARTER

MARCH 19, 1902

CHAPTER 181 OF THE LAWS OF 1902

AN ACT to amend chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," a Corporation now known as The New York Academy of Sciences and to extend the powers of said Corporation.

(Became a law March 19, 1902, with the approval of the Governor. Passed, three-fifths being present.)

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

SECTION I. The Corporation incorporated by chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," and formerly known by that name, but now known as The New York Academy of Sciences through change of name pursuant to order made by the supreme court at the city and county of New York, on January fifth, eighteen hundred and seventy-six, is hereby authorized and empowered to raise money for, and to erect and maintain, a building in the city of New York for its use, and in which also at its option other scientific societies may be admitted and have their headquarters upon such terms as said Corporation may make with them, portions of which building may be also rented out by said Corporation for any lawful uses for the purposes of obtaining income for the maintenance of such building and for the promotion of the objects of the Corporation; to establish, own, equip, and administer a public library, and a museum having especial reference to scientific subjects; to publish communications, transactions, scientific works, and periodicals; to give scientific instruction by lectures or otherwise; to encourage the advancement of scientific research and discovery, by gifts of money, prizes, or other assistance thereto. The building, or rooms, of said Corporation in the City of New York used exclusively for library or scientific purposes shall be subject to the provisions and be entitled to the benefits of subdivision seven of section four of chapter nine hundred and eight of the laws of eighteen hundred and ninety-six, as amended.

SECTION II. The said Corporation shall from time to time forever hereafter have power to make, constitute, ordain, and establish such by-laws and regulations as it shall judge proper for the election of its officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of officers and members thereof; for collecting dues and contributions towards the funds thereof; for regulating the times and places of meeting of said Corporation; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for managing or directing the affairs or concerns of the said Corporation: and may from time to time alter or modify its constitution, by-laws, rules, and regulations.

Section III. The officers of the said Corporation shall consist of a president and two or more vice-presidents, a corresponding secretary, a recording secretary, a treasurer, and such other officers as the Corporation may judge necessary; who shall be chosen in the manner and for the terms prescribed by the constitution of the said Corporation.

Section IV. The present constitution of the said Corporation shall, after the passage of this act, continue to be the constitution thereof until amended as herein provided. Such constitution as may be adopted by a vote of not less than three-quarters of such resident members and fellows of the said New York Academy of Sciences as shall be present at a meeting thereof, called by the Recording Secretary for that purpose, within forty days after the passage of this act, by written notice duly mailed, postage prepaid, and addressed to each fellow and resident member at least ten days before such meeting, at his last known place of residence, with street and number when known, which meeting shall be held within three months after the passage of this act, shall be thereafter the constitution of the said New York Academy of Sciences, subject to alteration or amendment in the manner provided by such constitution.

Section V. The said Corporation shall have power to consolidate, to unite, to co-operate, or to ally itself with any other society or association in the city of New York organized for the promotion of the knowledge or the study of any science, or of research therein, and for this purpose to receive, hold, and administer real and personal property for the uses of such consolidation, union, co-operation, or alliance subject to such terms and regulations as may be agreed upon with such associations or societies.

Section VI. This act shall take effect immediately.

State of New York,
Office of the Secretary of State.

I have compared the preceding with the original law on file in this office, and do hereby certify that the same is a correct transcript therefrom, and the whole of said original law.

Given under my hand and the seal of office of the Secretary of State, at the city of Albany, this eighth day of April, in the year one thousand nine hundred and two.

John T. McDonough,
Secretary of State.

CONSTITUTION

Adopted, April 24, 1902, and Amended at Subsequent Times

Article I. The name of this Corporation shall be The New York Academy of Sciences. Its object shall be the advancement and diffusion of scientific knowledge, and the center of its activities shall be in the City of New York.

Article II. The Academy shall consist of five classes of members, namely: Active Members, Fellows, Associate Members, Corresponding Members and Honorary Members. Active Members shall be the members of the Corporation who live in or near the City of New York, or who, having removed to a distance, desire to retain their connection with the Academy. Fellows shall be chosen from the Active Members in virtue of their scientific attainments. Corresponding and Honorary Members shall be chosen from among persons who have attained distinction in some branch of science. The number of Corresponding Members shall not exceed two hundred, and the number of Honorary Members shall not exceed fifty.

Article III. None but Fellows and Active Members who have paid their dues up to and including the last fiscal year shall be entitled to vote or to hold office in the Academy.

Article IV. The officers of the Academy shall be a President, as many Vice-Presidents as there are sections of the Academy, a Corresponding Secretary, a Recording Secretary, a Treasurer, a Librarian, an Editor, six elected Councilors and one additional Councilor from each allied society or association. The annual election shall be held on the third Monday in December, the officers then chosen to take office at the first meeting in January following.

There shall also be elected at the same time a Finance Committee of three.

Article V. The officers named in Article IV shall constitute a Council, which shall be the executive body of the Academy with general control over its affairs, including the power to fill *ad interim* any vacancies that may occur in the offices. Past Presidents of the Academy shall be *ex-officio* members of the Council.

Article VI. Societies organized for the study of any branch of science may become allied with the New York Academy of Sciences by consent of the Council. Members of allied societies may become Active Members of the Academy by paying the Academy's annual fee, but as members of an allied society they shall be Associate Members with the rights and privileges of other Associate Members, except the receipt of its publications. Each allied society shall have the right to delegate one of its members, who is also an Active Member of the Academy, to the Council of the Academy, and such delegate shall have all the rights and privileges of other Councilors.

Article VII. The President and Vice-Presidents shall not be eligible to more than one re-election until three years after retiring from office; the Secretaries and Treasurer shall be eligible to re-election without limitation. The President, Vice-Presidents and Secretaries shall be Fellows. The terms of office of elected Councilors shall be three years, and these officers shall be so grouped that two, at least one of whom shall be a Fellow, shall be elected and two retired each year. Councilors shall not be eligible to re-election until after the expiration of one year.

Article VIII. The election of officers shall be by ballot, and the candidates having the greatest number of votes shall be declared duly elected.

Article IX. Ten members, the majority of whom shall be Fellows, shall form a quorum at any meeting of the Academy at which business is transacted.

Article X. The Academy shall establish by-laws, and may amend them from time to time as therein provided.

Article XI. This Constitution may be amended by a vote of not less than three-fourths of the Fellows and three-fourths of the active members present and voting at a regular business meeting of the Academy, provided that such amendment shall be publicly submitted in writing at the preceding business meeting, and provided also that the Recording Secretary shall send a notice of the proposed amendment at least ten days before the meeting, at which a vote shall be taken, to each Fellow and Active Member entitled to vote.

BY-LAWS

As Adopted, October 6, 1902, and Amended at Subsequent Times

Chapter I

OFFICERS

1. *President.* It shall be the duty of the President to preside at the business and special meetings of the Academy; he shall exercise the customary duties of a presiding officer.

2. *Vice-Presidents.* In the absence of the President, the senior Vice-President, in order of Fellowship, shall act as the presiding officer.

3. *Corresponding Secretary.* The Corresponding Secretary shall keep a corrected list of the Honorary and Corresponding Members, their titles and addresses, and shall conduct all correspondence with them. He shall make a report at the Annual Meeting.

4. *Recording Secretary.* The Recording Secretary shall keep the minutes of the Academy proceedings; he shall have charge of all documents belonging to the Academy, and of its corporate seal, which he shall affix and attest as directed by the Council; he shall keep a corrected list of the Active Members and Fellows, and shall send them announcements of the Meetings of the Academy; he shall notify all Members and Fellows of their election, and committees of their appointment; he shall give notice to the Treasurer and to the Council of matters requiring their action, and shall bring before the Academy business presented by the Council. He shall make a report at the Annual Meeting.

5. *Treasurer.* The Treasurer shall have charge, under the direction of the Council, of all moneys belonging to the Academy, and of their investment. He shall receive all fees, dues and contributions to the Academy, and any income that may accrue from property or investment; he shall report to the Council at its last meeting before the Annual Meeting the names of members in arrears; he shall keep the property of the Academy insured, and shall pay all debts against the Academy the discharge of which shall be ordered by the Council. He shall report to the Council from time to time the state of the finances, and at the Annual Meeting shall report to the Academy the receipts and expenditures for the entire year.

6. *Librarian.* The Librarian shall have charge of the library, under the general direction of the Library Committee of the Council, and shall conduct all correspondence respecting exchanges of the Academy. He shall make a report on the condition of the library at the Annual Meeting.

7. *Editor.* The editor shall have charge of the publications of the Academy, under the general direction of the Publication Committee of the Council. He shall make a report on the condition of the publications at the Annual Meeting.

Chapter II

COUNCIL

1. *Meetings.* The Council shall meet once a month, or at the call of the President. It shall have general charge of the affairs of the Academy.

2. *Quorum.* Five members of the Council shall constitute a quorum.

3. *Officers.* The President, Vice-Presidents and Recording Secretary of the Academy shall hold the same offices in the Council.

4. *Committees.* The Standing Committees of the Council shall be: (1) an Executive Committee consisting of the President, Treasurer, and Recording Secretary; (2) a Committee on Publication; (3) a Committee on the Library, and such other committees as from time to time shall be authorized by the Council. The action of these committees shall be subject to revision by the Council.

Chapter III

FINANCE COMMITTEE

The Finance Committee of the Academy shall audit the Annual Report of the Treasurer, and shall report on financial questions whenever called upon to do so by the Council.

Chapter IV

ELECTIONS

1. *Active Members.* (*a*) Active Members shall be nominated in writing to the Council by at least two Active Members or Fellows. If approved by the Council, they may be elected at the succeeding business meeting.

(*b*) Any Active Member who, having removed to a distance from the city of New York, shall nevertheless express a desire to retain his connection with the Academy, may be placed by vote of the Council on a list of Non-Resident Members. Such members shall relinquish the full privileges and obligations of Active Members. (*Vide* Chapters V and X.)

2. *Associate Members.* Workers in science may be elected to Associate Membership for a period of two years in the manner prescribed for Active Members. They shall not have the power to vote and shall not be eligible to election as Fellows, but may receive the publications. At any time subsequent to their election they may assume the full privileges of Active Members by paying the dues of such Members.

3. *Fellows, Corresponding Members and Honorary Members.* Nominations for Fellows, Corresponding Members and Honorary Members may be made in writing either to the Recording Secretary or to the Council at its meeting prior to the Annual Meeting. If approved by the Council, the nominees shall then be balloted for at the Annual Meeting.

4. *Officers.* Nominations for Officers, with the exception of Vice-Presidents, may be sent in writing to the Recording Secretary, with the name of the proposer, at any time not less than thirty days before the Annual Meeting. Each section of the Academy shall nominate a candi-

date for Vice-President, who, on election, shall be Chairman of the section; the names of such nominees shall be sent to the Recording Secretary properly certified by the sectional secretaries, not less than thirty days before the Annual Meeting. The Council shall then prepare a list which shall be the regular ticket. This list shall be mailed to each Active Member and Fellow at least one week before the Annual Meeting. But any Active Member or Fellow entitled to vote shall be entitled to prepare and vote another ticket.

Chapter V

DUES

1. *Dues.* The annual dues of Active Members and Fellows shall be $10, payable in advance at the time of the Annual Meeting; but new members elected after May 1, shall pay $5 for the remainder of the fiscal year.

The annual dues of elected Associate Members shall be $3, payable in advance at the time of the Annual Meeting.

Non-Resident Members shall be exempt from dues, so long as they shall relinquish the privileges of Active Membership. (*Vide* Chapter X.)

2. *Members in Arrears.* If any Active Member or Fellow whose dues remain unpaid for more than one year, shall neglect or refuse to pay the same within three months after notification by the Treasurer, his name may be erased from the rolls by vote of the Council. Upon payment of his arrears, however, such person may be restored to Active Membership or Fellowship by vote of the Council.

3. *Renewal of Membership.* Any Active Member or Fellow who shall resign because of removal to a distance from the city of New York, or any Non-Resident Member, may be restored by vote of the Council to Active Membership or Fellowship at any time upon application.

Chapter VI

PATRONS, DONORS AND LIFE MEMBERS

1. *Patrons.* Any person contributing at one time $1,000 to the general funds of the Academy shall be a Patron and, on election by the Council, shall enjoy all the privileges of an Active Member.

2. *Donors.* Any person contributing $50 or more annually to the general funds of the Academy shall be termed a Donor and, on election by the Council, shall enjoy all the privileges of an Active Member.

3. *Life Members.* Any Active Member or Fellow contributing at one time $100 to the general funds of the Academy shall be a Life Member

and shall thereafter be exempt from annual dues; and any Active Member or Fellow who has paid annual dues for twenty-five years or more may, upon his written request, be made a life member and be exempt from further payment of dues.

Chapter VII

SECTIONS

1. *Sections.* Sections devoted to special branches of Science may be established or discontinued by the Academy on the recommendation of the Council. The present sections of the Academy are the Section of Astronomy, Physics and Chemistry, the Section of Biology, the Section of Geology and Mineralogy and the Section of Anthropology and Psychology.

2. *Organization.* Each section of the Academy shall have a Chairman and a Secretary, who shall have charge of the meetings of their Section. The regular election of these officers shall take place at the October or November meeting of the section, the officers then chosen to take office at the first meeting in January following.

3. *Affiliation.* Members of scientific societies affiliated with the Academy, and members of the Scientific Alliance, or men of science introduced by members of the Academy, may attend the meetings and present papers under the general regulations of the Academy.

Chapter VIII

MEETINGS

1. *Business Meetings.* Business meetings of the Academy shall be held on the first Monday of each month from October to May inclusive.

2. *Sectional Meetings.* Sectional meetings shall be held on Monday evenings from October to May inclusive, and at such other times as the Council may determine. The sectional meeting shall follow the business meeting when both occur on the same evening.

3. *Annual Meeting.* The Annual Meeting shall be held on the third Monday in December.

4. *Special Meetings.* A special meeting may be called by the Council, provided one week's notice be sent to each Active Member and Fellow, stating the object of such meeting.

Chapter IX

ORDER OF BUSINESS

1. *Business Meetings.* The following shall be the order of procedure at business meetings:

    1. Minutes of the previous business meeting.
    2. Report of the Council.
    3. Reports of Committees.
    4. Elections.
    5. Other business.

2. *Sectional Meetings.* The following shall be the order of procedure at sectional meetings:

    1. Minutes of the preceding meeting of the section.
    2. Presentation and discussion of papers.
    3. Other scientific business.

3. *Annual Meetings.* The following shall be the order of procedure at Annual Meetings:

    1. Annual reports of the Corresponding Secretary, Recording Secretary, Treasurer, Librarian, and Editor.
    2. Election of Honorary Members, Corresponding Members, and Fellows.
    3. Election of officers for the ensuing year.
    4. Annual address of the retiring President.

Chapter X

PUBLICATIONS

1. *Publications.* The established publications of the Academy shall be the *Annals* and the *Memoirs.* They shall be issued by the Editor under the supervision of the Committee on Publications.

2. *Distribution.* One copy of all publications shall be sent to each Patron, Life Member, Active Member and Fellow; *provided,* that upon inquiry by the Editor such Members or Fellows shall signify their desire to receive them.

3. *Publication Fund.* Contributions may be received for the publication fund, and the income thereof shall be applied toward defraying the expenses of the scientific publications of the Academy.

Chapter XI

GENERAL PROVISIONS

1. *Debts.* No debts shall be incurred on behalf of the Academy, unless authorized by the Council.

2. *Bills.* All bills submitted to the Council must be certified as to correctness by the officers incurring them.

3. *Investments.* All the permanent funds of the Academy shall be invested in United States or in New York State securities or in first mortgages on real estate, provided they shall not exceed sixty-five per cent. of the value of the property, or in first-mortgage bonds of corporations which have paid dividends continuously on their common stock for a period of not less than five years. All income from patron's fees, life-membership fees and donor's fees shall be added to the permanent fund.

4. *Expulsion, etc.* Any Member or Fellow may be censured, suspended or expelled for violation of the Constitution or By-Laws, or for any offence deemed sufficient, by a vote of three-fourths of the Members and three-fourths of the Fellows present at any business meeting, provided such action shall have been recommended by the Council at a previous business meeting, and also, that one month's notice of such recommendation and of the offence charged shall have been given the Member accused.

5. *Changes in By-Laws.* No alteration shall be made in these By-Laws unless it shall have been submitted publicly in writing at a business meeting, shall have been entered on the Minutes with the names of the Members or Fellows proposing it, and shall be adopted by two-thirds of the Members and Fellows present and voting at a subsequent business meeting.

MEMBERSHIP OF THE

NEW YORK ACADEMY OF SCIENCES

HONORARY MEMBERS

31 December, 1913.

Elected.	
1912.	Frank D. Adams, Montreal, Canada.
1898.	Arthur Auwers, Berlin, Germany.
1889.	Charles Barrois, Lille, France.
1907.	William Bateson, Cambridge, England.
1910.	Theodor Boveri, Würzburg, Germany.
1901.	Charles Vernon Boys, London, England.
1904.	W. C. Brögger, Christiania, Norway.
1876.	W. Boyd Dawkins, Manchester, England.
1913.	Charles Déperet, Lyons, France.
1902.	Sir James Dewar, Cambridge, England.
1901.	Emil Fischer, Berlin, Germany.
1876.	Sir Archibald Geikie, Haslemere, Surrey, England
1901.	James Geikie, Edinburgh, Scotland.
1898.	Sir David Gill, London, England.
1909.	K. F. Göbel, Munich, Germany.
1889.	George Lincoln Goodale, Cambridge, Mass.
1909.	Paul von Groth, Munich, Germany.
1894.	Ernst Häckel, Jena, Germany.
1912.	George E. Hale, Mt. Wilson, Calif.
1899.	Julius Hann, Vienna, Austria.
1898.	George W. Hill, West Nyack, N. Y.
1896.	Ambrosius A. W. Hubrecht, Utrecht, Netherlands.
1896.	Felix Klein, Göttingen, Germany.
1909.	Alfred Lacroix, Paris, France.
1876.	Viktor von Lang, Vienna, Austria.
1898.	E. Ray Lankester, London, England.
1880.	Sir Norman Lockyer, London, England.
1911.	Ernst Mach, Munich, Germany.
1912.	Iliya Metchnikof, Paris, France.
1912.	Sir John Murray, Edinburgh, Scotland.[1]
1898.	Fridtjof Nansen, Christiania, Norway.
1908.	Wilhelm Ostwald, Gross-Bothen, Germany.
1898.	Albrecht Penck, Berlin, Germany.
1898.	Wilhelm Pfeffer, Leipzig, Germany.

[1] Deceased.

Elected.

1900. Edward Charles Pickering, Cambridge, Mass.
1911. Edward Bagnall Poulton, Oxford, England.
1913. Sir David Prain, Kew, England.
1901. Sir William Ramsay, London, England.
1899. Lord Rayleigh, Witham, Essex, England.
1898. Hans H. Reusch, Christiania, Norway.
1887. Sir Henry Enfield Roscoe, London, England.
1887. Heinrich Rosenbusch, Heidelberg, Germany.[1]
1912. Sho Watasé, Tokyo, Japan.
1904. Karl von den Steinen, Berlin, Germany.
1896. Joseph John Thomson, Cambridge, England.
1900. Edward Burnett Tylor, Oxford, England.
1904. Hugo de Vries, Amsterdam, Netherlands.
1907. James Ward, Cambridge, England.
1909. August Weissmann, Freiburg, Germany.
1904. Wilhelm Wundt, Leipzig, Germany.

CORRESPONDING MEMBERS

31 December, 1913.

1883. Charles Conrad Abbott, Trenton, N. J.
1891. José G. Aguilera, Mexico City, Mexico.
1890. William De Witt Alexander, Honolulu, Hawaii.
1899. C. W. Andrews, London, England.
1876. John Howard Appleton, Providence, R. I.
1899. J. G. Baker, Kew, England.
1898. Isaac Bagley Balfour, Edinburgh, Scotland.
1878. Alexander Graham Bell, Washington, D. C.
1867. Edward L. Berthoud, Golden, Colo.
1897. Herbert Bolton, Bristol, England.
1899. G. A. Boulenger, London, England.
1874. T. S. Brandegee, Berkeley, Calif.
1884. John C. Branner, Stanford University, Calif.
1894. Bohuslay Brauner, Prague, Bohemia.
1874. William Brewster, Cambridge, Mass.
1898. T. C. Chamberlin, Chicago, Ill.
1876. Frank Wigglesworth Clarke, Washington, D. C.
1891. L. Clerc, Ekaterinburg, Russia.
1877. Theodore B. Comstock, Los Angeles, Calif.
1868. M. C. Cooke, London, England.

[1] Deceased.

ELECTED.

1876. H. B. CORNWALL, Princeton, N. J.
1880. CHARLES B. CORY, Boston, Mass.
1877. JOSEPH CRAWFORD, Philadelphia, Pa.
1895. HENRY P. CUSHING, Cleveland, O.
1879. T. NELSON DALE, Pittsfield, Mass.
1870. WILLIAM HEALEY DALL, Washington, D. C.
1885. EDWARD SALISBURY DANA, New Haven, Conn.
1898. WILLIAM M. DAVIS, Cambridge, Mass.
1894. RUTHVEN DEANE, Chicago, Ill.
1899. CHARLES DÉPERET, Lyons, France.
1890. ORVILLE A. DERBY, Rio de Janeiro, Brazil.
1899. LOUIS DOLLO, Brussels, Belgium.
1876. HENRY W. ELLIOTT, Lakewood, O.
1880. JOHN B. ELLIOTT, Tulane Univ., La.
1869. FRANCIS E. ENGELHARDT, Syracuse, N. Y.
1879. HERMAN LE ROY FAIRCHILD, Rochester, N. Y.
1879. FRIEDRICH BERNHARD FITTICA, Marburg, Germany.
1885. LAZARUS FLETCHER, London, England.
1899. EBERHARD FRAAS, Stuttgart, Germany.
1879. REINHOLD FRITZGARTNER, Tegucigalpa, Honduras.
1870. GROVE K. GILBERT, Washington, D. C.
1858. THEODORE NICHOLAS GILL, Washington, D. C.
1865. CHARLES A. GOESSMAN, Amherst, Mass.
1888. FRANK AUSTIN GOOCH, New Haven, Conn.
1868. C. R. GREENLEAF, San Francisco, Calif.
1883. Marquis ANTONIO DE GREGORIO, Palermo, Sicily.
1869. R. J. LECHMERE GUPPY, Trinidad, British West Indies.
1898. GEORGE E. HALE, Mt. Wilson, Calif.
1882. Baron ERNST VON HESSE-WARTEGG, Lucerne, Switzerland.
1867. C. H. HITCHCOCK, Honolulu, H. I.
1900. WILLIAM HENRY HOLMES, Washington, D. C.
1890. H. D. HOSKOLD, Buenos Ayres, Argentine Republic.
1896. J. P. IDDINGS, Brinklow, Md.
1875. MALVERN W. ILES, Dubuque, Ia.
1899. OTTO JÄKEL, Greifswald, Germany.
1876. DAVID STARR JORDAN, Stanford University, Calif.
1876. GEORGE A. KOENIG, Houghton, Mich.
1888. Baron R. KUKI, Tokyo, Japan.
1876. JOHN W. LANGLEY, Cleveland, O.
1876. S. A. LATTIMORE, Rochester, N. Y.

ELECTED.

1894. WILLIAM LIBBEY, Princeton, N. J.
1899. ARCHIBALD LIVERSIDGE, London, England.
1876. GEORGE MACLOSKIE, Princeton, N. J.
1876. JOHN WILLIAM MALLET, Charlottesville, Va.
1891. CHARLES RIBORG MANN, Chicago, Ill.
1867. GEORGE F. MATTHEW, St. John, N. B., Canada.
1874. CHARLES JOHNSON MAYNARD, West Newton, Mass.
1874. THEODORE LUQUEER MEAD, Oviedo, Fla.
1888. SETH E. MEEK, Chicago, Ill.
1892. J. DE MENDIZÁBAL-TAMBORREL, Mexico City, Mexico.
1874. CLINTON HART MERRIAM, Washington, D. C.
1898. MANSFIELD MERRIAM, South Bethlehem, Pa.
1878. CHARLES SEDGWICK MINOT, Boston, Mass.
1876. WILLIAM GILBERT MIXTER, New Haven, Conn.
1890. RICHARD MOLDENKE, Watchung, N. J.
1895. C. LLOYD MORGAN, Bristol, England.
1864. EDWARD S. MORSE, Salem, Mass.
1898. GEORGE MURRAY, London, England.
——. EUGEN NETTO, Giessen, Germany.
1866. ALFRED NEWTON, Cambridge, England.
1897. FRANCIS C. NICHOLAS, New York, N. Y.
1882. HENRY ALFRED ALFORD NICHOLLS, Dominica, B. W. I.
1880. EDWARD J. NOLAN, Philadelphia, Pa.
1876. JOHN M. ORDWAY, New Orleans, La.
1900. GEORGE HOWARD PARKER, Cambridge, Mass.
1876. STEPHEN F. PECKHAM, New York, N. Y.
1877. FREDERICK PRIME, Philadelphia, Pa.
1868. RAPHAEL PUMPELLY, Newport, R. I.
1876. B. ALEX. RANDALL, Philadelphia, Pa.
1876. IRA REMSEN, Baltimore, Md.
1874. ROBERT RIDGWAY, Washington, D. C.
1886. WILLIAM L. ROBB, Troy, N. Y.
1876. SAMUEL P. SADTLER, Philadelphia, Pa.
1899. D. MAX SCHLOSSER, Munich, Germany.
1898. W. B. SCOTT, Princeton, N. J.
1894. W. T. SEDGWICK, Boston, Mass.
1876. ANDREW SHERWOOD, Portland, Ore.
1883. J. WARD SMITH, Newark, N. J.
1895. CHARLES H. SMYTH, Jr., Princeton, N. J.
1890. J. SELDEN SPENCER, Tarrytown, N. Y.

Elected.

1896. Robert Stearns, Los Angeles, Calif.
1890. Walter Le Conte Stevens, Lexington, Va.
1876. Francis H. Storer, Boston, Mass.
1885. Rajah Sourindro Mohun Tagore, Calcutta, India.
1893. J. P. Thomson, Brisbane, Queensland, Australia.
1899. R. H. Traquair, Colinton, Scotland.
1877. John Trowbridge, Cambridge, Mass.
1876. D. K. Tuttle, Philadelphia, Pa.
1871. Henri Van Heurck, Antwerp, Belgium.
1900. Charles R. Van Hise, Madison, Wis.
1867. Addison Emery Verrill, New Haven, Conn.
1890. Anthony Wayne Vogdes, San Diego, Calif.
1898. Charles Doolittle Walcott, Washington, D. C.
1876. Leonard Waldo, New York, N. Y.
1897. Stuart Weller, Chicago, Ill.
1874. I. C. White, Morgantown, W. Va.
1898. Henry Shaler Williams, Ithaca, N. Y.
1898. N. H. Winchell, Minneapolis, Minn.
1866. Horatio C. Wood, Philadelphia, Pa.
1899. A. Smith Woodward, London, England.
1876. Arthur Williams Wright, New Haven, Conn.
1876. Harry Crècy Yarrow, Washington, D. C.

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†Ford, James B.
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Friedrick, J. J.[1]

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