ANNALS

OF THE

NEW YORK ACADEMY OF SCIENCES

VOLUME XXVII

NEW YORK
PUBLISHED BY THE ACADEMY
1916, 1917

Editor

RALPH W. TOWER

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DATES OF PUBLICATION AND EDITIONS OF THE BROCHURES

	Edition
Pp. 1–15, 25 January, 1916	1175 copies
Pp. 17–22, 25 January, 1916	1100 copies
Pp. 23–29, 28 January, 1916	1175 copies
Pp. 31–38, 4 May, 1916	1050 copies
Pp. 39–191, 12 June, 1916	1050 copies
Pp. 193–203, 9 August, 1916	1100 copies
Pp. 205–214, 31 January, 1917	1500 copies
Pp. 215–243, 2 August, 1917	1500 copies
Pp. 245–336, 30 November, 1917	1500 copies

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SOME REMARKS UPON MATTHEW'S "CLIMATE AND EVOLUTION"

BY

T. Barbour

WITH SUPPLEMENTAL NOTE

BY

W. D. Matthew

NEW YORK
PUBLISHED BY THE ACADEMY
25 January, 1916

THE NEW YORK ACADEMY OF SCIENCES

(LYCEUM OF NATURAL HISTORY, 1817-1876)

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. XXVII, pp. 1-15. 25 January, 1916]

SOME REMARKS UPON MATTHEW'S "CLIMATE AND EVOLUTION"[1]

BY T. BARBOUR

WITH SUPPLEMENTARY NOTE

BY W. D. MATTHEW

(*Presented by title before the Academy, 13 December, 1915*)

"Climate and Evolution," which is really more than its title would imply an essay on the origin and dispersal of vertebrate life, appeared in February, 1915, from the pen of Dr. W. D. Matthew.[2] It is by far the most scholarly and carefully constructed essay of its kind which has appeared and it demands a careful reading by all who take interest in perhaps the greatest of biological problems—the why and wherefore of the dispersal of animal life as we find it to-day and the past history of present conditions.

Matthew's thesis, in a few words, is that the permanence of the continents and ocean basins is a surely established fact, that cyclical climatic change has been the principal known cause of the present distribution of land vertebrates, and that this distribution has been effected by successive southward migrations from a holarctic center of dispersion, and that the impetus for these migrations is to be found in the theories of the "Alternations of moist and uniform with arid and zonal climates, as elaborated by Chamberlin." There is small occasion for me to review or criticise the great bulk of evidence which Matthew has presented, specially where he has drawn upon his profound knowledge of recent and fossil mammals. In the main his contentions are highly convincing, especially where he also draws conclusions from the mammals, a group for which geologic record is adequate in comparison with the fragmentary evidence regarding the history of recent birds, recent reptiles and amphibians. With some of these groups, as, for instance, Hylids and Cystignathids, it is hard to rid oneself of the belief that their origin was antarctic and not holarctic, for the northern outpost species seem to be so obviously the depauperate offshoots of the elaborate southern stock. Matthew, however, would argue by analogy with mammalian evidence that these species are

[1] Manuscript received by the Editor 22 October, 1915.
[2] Ann. N. Y. Acad. Sci., vol. 24, pp. 171-318. 1915.

reëntrants into the area of origin, and that the great result of speciation which we see now in the southern headquarters of Hylids and Cystignathids shows that this region was peripheral in relation to their area of origin. The steps of reasoning whereby Matthew arrives at these conclusions are carefully presented in his essay and there is no object in recounting them here.

It is of the general question of land bridges and of the relation which some islands bear to continents that I have been thinking for some time, and it is only because I have had some field experience and have given thought to these matters that I have the temerity to take issue with Dr. Matthew, knowing full well that many will maintain that his opinion outweighs mine—a possible assertion I am by no means ready to deny.

I take exception to statements such as this, where in speaking of land bridges (p. 179) Matthew says, "I can see no good reason why the only animals which availed themselves of such continental bridges should be the ones which might be accounted for in other ways, while those which would furnish conclusive proof *are invariably absent.*" (Italics are mine.) I have maintained elsewhere that a waif fauna is easily recognized as such, and that the presence of burrowing amphibia, onychophores, cyprinodont fishes and many other groups of delicate organisms which are balanced to one particular environment cannot by any stretch of the imagination be distributed by "flotsam and jetsam" methods; and further that the element of the vast extent of geologic time does not in any way affect the probability of such dispersal, since it cannot be supposed *ever* to occur.

Again, on page 187, we read that Austromalaya is the debatable ground between the Oriental and the very distinct Australian region; but that the consensus of opinion classes it by preference with the Australian. It includes, we are told, Celebes, the Moluccas, Timor and the smaller islands and is separated from the Oriental region by "Wallace's Line." This is surely a step backward, for "Wallace's Line" marks the limit of but a small fraction of the whole species total of the Indonesian fauna, while the area from the Lesser Sunda Islands and Celebes on the one hand to Papuasia on the other represents a great transition zone, where a dominance of Malayan types may be found in the western part which merges into a predominance of Australian types in Papua. There is no real boundary line in the entire area and no reason to expect one.

Again Dr. Matthew in his "Summary of Evidence" (p. 308) states that "the continental and oceanic areas are now maintained at their different levels chiefly through isostatic balance and it is difficult to believe that they could formerly have been reversed in any extensive degree."

Then, on page 309: "A rise of 100 fathoms would unite all the continents and continental islands, except perhaps Australia, into a single mass, but would leave Antarctica, New Zealand, Madagascar, Cuba and many smaller islands separate." These four areas Matthew believes to have been always isolated islands, and if we can show a probability that any one of them was continental, we can at least make more reasonable a proposition that they all were once united to some other continental land. This point will be returned to later on.

Now a word regarding isostasy. There is hardly a principle in geology concerning which there is greater uncertainty among geologists than the matter of isostatic balance. Only one thing is sure, isostasy must meet and conform to known or presumably known facts, and the fact that fundamental changes have taken place in the form of the earth's surface in recent geologic time is not to be denied. Such features as the Great Rift Valley of Africa and its continuation, the Red Sea and the Dead Sea, the Black Sea, the Basin of the Mediterranean, are held now by geologists to be the results of nothing but gigantic and not at all ancient down-thrown fault-blocks. For other examples of changes of land and sea level with relation to each other, the Valley of the Po and the Central Valley of California are good evidence. The argument of isostatic balance may probably be held to control the conditions in the Pacific Basin as a whole, but isostasy cannot be used effectively as an argument in a relatively small area anywhere. Professor R. A. Daly tells me that there is clear evidence of the fragmentation of a great land mass, including the Fiji Islands and New Caledonia, but that there is no evidence known at present of such a condition outside of a line joining Yap, in the Caroline Islands, the Fijis, Kermadecs and New Zealand. Besides this radiolarian ooze has long been known from Barbadoes, Trinidad, Aruba, Buen Ayre and Curaçoa, supposedly only to be derived from the deep sea, but the origin of this series of deposits has been somewhat in dispute. Two recent papers by Dr. G. A. F. Molengraaff, however, describe deposits of which there can hardly be any question whatever; one is "On Oceanic Deep Sea Deposits in Central Borneo,"[3] while the other is entitled "Over mangaan Knollen in mesozoischen diepzeeafzettingen van Borneo, Timor en Rotti, hun beteekenis en hun wijzer van Opstaan."[4] These papers show that on the islands of Borneo, Timor and Rotti, at an elevation of about 4000 feet, very extensive deposits occur which a microscopical examination shows to be composed of radiolaria, together with the manganese nodules so characteristic of the deep sea. In other words, Molengraaff

[3] Kon. Ak. Wet. Amsterdam, Reprint from Proc. of meeting June 26, 1909, pp. 141-147. [Reprint, pp. 1-7.]
[4] Kon. Ak. Wet. Amsterdam, vol. 23, pp. 1058-1073. [Reprint, pp. 1-16.]

has found an extensive area of deep sea floor raised to 4000 feet above the present sea level. On the southeast coast of Africa, W. M. Davis noticed the truncation by the present shore line of extensive concentric terraces, traceable far inland, which could only mean the down-faulting of a gigantic block of material to bring the shore line into its present state. It will be said at once that some of these changes of level have taken place in zones known to be in incomplete isostatic adjustment, but this is a matter of no moment whatsoever in comparison with the fact that change of level may be found to have occurred in the very areas where the islands under discussion are to be found. Celebes does not lie upon the continental shelf and yet the island has an obviously continental fauna, and Dr. Matthew has told me himself that Celebes has been a source of no small worry to him. Cuba has similarly a large fauna, derived from the American continent, although it does not lie upon the continental shelf. Vaughan, a thoroughly conservative observer, believes (in litt.) that Cuba was quite possibly separated, by the down-faulting of blocks of material, from both Haiti and the mainland. Dr. Matthew (in litt.) says: "The fault block theory is of course a very familiar one; its application to continental movements is undoubtedly extensive, although it is just now somewhat of a fetish among stratigraphers, as folds were fifty years ago. But on land the great fault blocks are largely compensated by erosion, so that they do not involve so extensive a displacement of adjoining surfaces as one might at first suppose. Their application to explain submarine conditions where such compensation does not occur brings them into an apparent conflict with isostatic adjustments. Considering that we cannot possibly *prove* their responsibility for the sudden changes from shallow sea to abyssal depths in any case, I am inclined to avoid hasty ascription to such features as block-faulting. I have passed beyond the stage of immaturity when one is unreasonably certain about things." I can only add that I am as far from being unreasonably certain regarding isostatic adjustments in general as Dr. Matthew is regarding marine down faults. To the zoölogist these geologic problems seem so differently interpreted by different and equally gifted and trustworthy students that one is inclined to relegate them all to the limbo of where "you pay your money and take your choice."

Vastly different, however, is the matter of the zoölogic evidence presented by the faunas of some islands as indicative of the island's geologic or geographic history. Dr. Matthew lays great stress upon the importance of the mammalian element in the fauna. Here a word of caution is not amiss, for mammals act queerly upon islands and often have a way of being most strangely absent, as this is the group which has greatest difficulty in surviving in a limited area. Trinidad, a large island separated by a very narrow strait from Venezuela, has a reasonably full quota of mammalian inhabitants, while the large and heavily wooded island of San Miguel, just off the coast of Panama, has but a few small mammals, quite a contrast to Coiba Island, farther north off Honduras, where even a peculiar deer is known still to occur. Gorgona Island, off Colombia, also with luxuriant vegetation, has a peculiar Cebus (*Cebus curtus* Bangs), a peculiar Proechimys, and so far as known no other mammals. Yet these differences are all among islands on the shelf and near or fairly near the shore; and I could multiply the examples!

Now I do not believe, with Matthew, that the Antilles are oceanic islands—islands which have received their fauna by fortuitous transportal. My reasons for thinking as I do are these: First, I believe that the islands of the Antillean chain have too evenly distributed and homogeneous a fauna for it all to have been fortuitously derived; secondly, I consider the fauna to be composed of too many different animal phyla; and thirdly I believe that many of these elements are not of a nature to have withstood "flotsam or jetsam" dispersal. We must now consider Matthew's exposition of the natural raft hypothesis (p. 206 *et seq.*). He states: "1) Natural rafts have been several times reported as seen over a hundred miles off the mouths of the great tropical rivers such as the Ganges, Amazon, Congo and Orinoco. For one such raft observed, a hundred have probably drifted out that far unseen or unrecorded before breaking up." This is obvious and undoubted. But, and this is most important, these rafts, even the very large ones, float low in the water; they soon become soaked with salt water in a calm sea, rippled over or broken over if the sea be choppy or rough as it is in the trade wind or monsoon belts. Only organisms or their eggs which are encapsulated or otherwise naturally resistant can withstand these conditions. Molluscs are stimulated to activity by dampening, but most are killed by salt water—although some such as Cerion are resistant. Scincs and Gekkos show by their distribution that they may be carried about in this way. Amphibians, amphisbænians, naked gastropods, earthworms, fresh-water fishes or crayfishes, Peripatus and a host of such delicate creatures simply cannot withstand salt water. No such creatures have ever been observed upon any raft, of the very few recorded, and to transport cyprinodonts, ampullarias and the host of other fresh-water types one meets with in Cuban ponds, for instance, the raft would have to include a puddle, at least, of fresh water. Supposing that an amphisbænian, to take a good example, withstood an ocean voyage upon a raft, how would the landing take place? The raft would have to make a haven and then ground in such a way that a very delicate, blind and legless lizard would be enabled to reach a suitable environment on shore. I only ask the reader to tramp West Indian shores with this in mind. If a pair or a gravid female did not make the voyage the process would have to be repeated promptly. Now consider the number of rafts each of which would have to carry an amphibian or a pair of them and which would have to start on their journeys before one would reach shore so as to permit a landing such as I have indicated Think of the number broken up at sea, and the still greater number broken up on a tropic beach—where the sun would instantly kill crawling amphisbænians—and we see at once how excessively improbable is a single occurrence such as this. But the important point is that five West Indian Islands support peculiar amphisbænians; two species occur upon Cuba, two others related to these two on Haiti and two others similarly related to the Haitian types on Porto Rico, while but one type is as yet known upon St. Thomas and Sta. Cruz. To account for the presence of these creatures, then, eight practically inconceivable voyages must be postulated, and I have only cited one improbability out of many hundred necessary to derive all the organisms practically or wholly incapable of such sea travel and which are found in the Greater Antilles. A few such cases as Amphisbæna settle the status of the greater Antillean fauna to my mind absolutely, paucity of mammals and possibly disputable geologic evidence to the contrary notwithstanding.

Matthew's second premise is: "2) The time of such observation of rafts covers about three centuries (I set aside the period of rare and occasional exploring voyages). The duration of Cenozoic time may be assumed at three million years (Walcott's estimate)." But is it not true that this multiplication of time or any other, of course, affects only the number of rafts and does not in any way alter the resistance to raft conditions of the creatures which I have already chosen above as examples or the possibility of their being able to swim. It really carries no weight in this connection.

Matthew's third point: "3) Living mammals have been occasionally observed in such records of natural rafts. Assume the chance of their occurrence (much greater than of their presence being noted) at one in a hundred." We readily agree to the assumption and know that during the few years of human observation rafting mammals have been observed. It occurs to us, however, that multiplying the three hundred years' time of human voyages by the ten thousand necessary to occupy even the short Cenozoic period and then with this condition met, we find mammals *infinitely rarer* upon all islands than they should be if rafted according to Matthew's postulate. Similarly we find many of the reptiles most capable of withstanding transport by rafts conspicuously absent in the West Indies; for example, Basiliscus, almost semiaquatic, is absent in the Antilles, as Varanus is absent upon Madagascar: they were possibly derived in common with many other of the islands' original continental inhabitants and have failed to survive. We know that some edentates and a few rodents have become extinct in the West Indies, some within the last half century; why, in some cases, we cannot guess; probably more have gone the same way, of which we have unfortunately no fossil remains. So also the boa-constrictor, which has been observed to be carried once to St. Vincent from the Orinoco and which has probably come comparatively often, has never succeeded in establishing itself. Why some types fail to survive upon islands while others of apparently similar habit flourish is one of the enigmas for which no mite of answer has appeared. Matthew's arguments, which he numbers 4 and 5, may be considered together: "4) Three hundred miles drift would readily reach any of the larger oceanic islands except New Zealand. Assume as one in ten the probability that the raft drifted in such a direction as to reach dry land within three hundred miles. 5) In case such animals reached the island shores and the environment afforded them a favorable opening, the propagation of the race would require either two individuals of different sexes or a gravid female. Assume the probability of any of the passengers surviving the dangers of landing as one in three (by being drawn in at the mouth of some tidal river or protected inlet), of landing at a point where the environment was sufficiently favorable as one in ten, the chances of two individuals of different sexes being together might be assumed to be one in ten, the alternate of a gravid female as one in five. The chance of the two happening would be $1/10 + 1/5 = 3/10$. The chance of the species obtaining a foothold would then be $3/10 + 1/3 + 1/10 = 1/100$." He then continues, "If then we allow that ten such cases of natural rafts far out at sea have been reported, we may concede that 1000 have probably occurred in three centuries and 30,000,000 during the Cenozoic. Of these rafts, only 3,000,000 will have had living mammals upon them; of these only 30,000 will have reached land, and in only 300 of these cases will the species have established a foothold. This is quite sufficient to cover the dozen or two cases of Mammalia on the larger oceanic islands.

"I have considered the case only in relation to small mammals. With reptiles and invertebrates, the probabilities in the case vary widely in different groups, but in almost every instance they would be considerably greater than with mammals. The chance for transportation and survival would be larger and the geologic time limit in many instances much longer. Wind, birds, small floating drift and other methods of accidental transportation may have played a more important part with invertebrates, although they cannot be invoked to account for the distribution of vertebrates. The much larger variety and wider distribution on infra-mammalian life in oceanic islands is thus quite to be expected. And the extent and limits of such distribution are in obviously direct accord with the opportunities for over-sea transportation in different groups."

In the estimate which Matthew has made there seems to be an obvious error, for should we postulate 1000 rafts in 300 years we would have 10,000,000 rafts during the 3,000,000 years of Cenozoic time, not 30,000,000 as Matthew has it, and the chances of the whole concatenation of events are reduced by 66 per cent. But even this reduced estimate would if true bring more mammals to most islands than we find. Let us, however, for the sake of argument, admit that some mammals might be transported in this way, is the premise true that other creatures will be more easily carried? Some will, and these types by their haphazard occurrence can now be recognized easily; others most certainly will not. Matthew has not realized the enormous sum total of different species which go to make up the fauna of such islands as Cuba and Haiti. Such a vast number of species would require squadrons of rafts at frequent intervals, even if only ancestral stocks were transported from which many species arose after coming to the island by some sort of adaptive radiation. Another important point has also been missed. Almost all of these isolated groups of individuals have grown to be well differentiated island species. Distinct from the related forms of the mainland and neighboring islands, they represent types evolved in complete isolation; an occasional raft bearing individuals from the parent stock would by preventing breeding in, at least in some cases, prevent speciation by isolation taking place.

Let us for a moment consider the Antillean chain as a whole; it is utterly impossible that ocean currents could now or in the past have brought rafts with equal frequency to all parts of this island arc, and yet the same types reappear upon island after island all the way from Cuba to Grenada. Rafting from island to island could certainly not have occurred, since there could never have been large rivers on them had they always retained their present size. The fauna is far larger in number of species upon the Greater Antilles than upon the Lesser, as the conditions favorable for the survival of species are obviously better upon the large islands with their luxuriant vegetation than upon such barren islets as, for example, Sombrero or Redonda. The types, however, which have been able to survive upon Sombrero or Saba are just those which are found, along with many others, upon Cuba or Haiti. In my "Herpetology of

Jamaica" and "Zoögeography of West Indian Reptiles," I have gone into this matter in detail and there is no need of repeating what has been said there. This homogeneity of the fauna is the best possible proof that winds (tornados, hurricanes, etc.), birds, small floating drift, etc., have played no considerable part in populating the island by carrying eggs or adults, since it is inconceivable that by these means the same improbable choice of passengers would be carried to so many islands.

Matthew, upon the basis of the mammalian fauna of Madagascar entirely, he believes, derivable from a few waifs, and from the fact that the island is not upon the present continental shelf, concludes that it is an oceanic island. We may grant that all the lemurs have radiated from a single type, and this may have been a waif type—all this for the sake of argument—but what does the rest of the fauna show? We find abundant amphibians of many different families, as well as a great host of other land and fresh water organisms which cannot by any stretch of the imagination be considered as more probably capable of surviving raft transport than mammals, nor in very many cases of possibly surviving such transportation at all. Yet such types as these are most abundant upon Madagascar, in individuals and in species—species representing wholly unrelated mainland stocks and not those which might possibly have arisen after coming to the island.

My friend Dr. G. M. Allen has contributed the following note regarding Madagascar which is interesting in this connection. He writes me: "The total absence from Madagascar of any native species of the typical Murinæ seems to be a striking bit of negative evidence against a chance population of the island. All the nine genera of indigenous rodents are Cricetine in their affinity, though now considered to represent a special subfamily by themselves—Nesomyinæ. The Cricetine-like rodents are abundant still in the Americas, less so in number of species in northern Eurasia. The African Lophiomys is nearly related. If we consider the more specialized typical Murinæ as representing a later development of the Muridæ, it is easy to account for their absence from America, if formerly, as now, their northward range did not extend to the East Siberian region, whence they could have crossed by land bridges if such existed. That no member of so widespread and successful a type in the Old World as Mus (in the broad sense) has reached Madagascar, it seems evident that it is because none have been able to cross the intervening water. If nine distinct genera of Cricetine-like rats or their ancestor or ancestors could have reached Madagascar by chance methods, it seems inconceivable that no single Murine could have done so, despite the great adaptability and abundance of the representatives of this group. The most attractive explanation of this fact is that the more primitive Cricetine-like rodents reached Madagascar by land connection from Africa and that they were subsequently isolated there before the advent of the more specialized and successful Murinæ, which have now totally replaced them on the mainland."

So much for the question of rafting—some creatures can be carried and some—many more—cannot survive such conditions. We may recognize by their haphazard distribution and by their habits in the field those waifs which can withstand raft transport. Yet even these resistant types are very often strangely absent; there are no Varanids in Madagascar, and yet we should naturally suppose that they would be among the very first immigrants by raft carriage.

This whole question is really but a side issue with Matthew. He is far more absorbed in other problems; hence it is only fair to say that this island question is of secondary interest to him. Dr. Matthew's masterly handling of his chapters dealing with mammals is beyond praise. He has surely shown that the present distribution of most if not all of the recent mammal groups may be plausibly explained without having recourse to postulating extensive changes of land forms. But Matthew deals with some other matters as one without authority, and one feels that his opinions would be different had he seen and not merely read about the rafts, and the landings of the rafts, of which he must perforce write to explain his ideas.

Many will notice trifling inaccuracies in the text, such as the statement that the large ground-birds of modern times are "to-day peculiarly inhabitants of arid regions." There is the New Zealand Kiwi in the rank damp fern forest and the host of different cassowaries in Ceram, the Papuan Islands, New Britain, Queensland, and anyone who has ever tried to hunt cassowary knows how well they are adapted to getting about in the densest jungle in the world. However, such points are of so small import that it is hardly worth while mentioning them. My final word is not to advise but to adjure everyone who aims at a wider knowledge of natural history to read Dr. Matthew's paper.

SUPPLEMENTARY NOTE [5]

By W. D. Matthew

Before replying to Dr. Barbour's criticism I will say that it is of the sort that is peculiarly welcome, not merely because of its courteous and considerate tone, but because of the author's wide field experience and knowledge of the practical conditions and circumstances of environment that govern the probabilities of any theories of distribution. However we may differ in our interpretation of the evidence, we agree in emphasizing these factors, in the impossibility of solving such problems by the study of any one group of animals, and especially in the need for securing more complete distributional data, towards obtaining which he has devoted so much time and energy.

Many a false theory gets crystallized by time and absorbed into the body of scientific doctrine through lack of adequate criticism when it is formulated. I should be very sorry to see that happen to the views that I have maintained and hope that adequate and competent criticism will serve to sift out truth from error before they are either adopted or discarded.

Concerning the question of isostatic adjustment I do not think it necessary to make any especial comments. I stated in the outset that I was applying the geological views set forth by Chamberlin and others. The evidence that Barbour cites was known to me and is covered by the qualifying phrases that I used; but the general discussion of the permanence of ocean basins I shall continue to avoid.

Dr. Barbour devotes considerable space to a criticism of my attempt at a statistical presentation of the possibilities of "rafting." He is indeed far less critical of its assumptions than I am. I tried to make it clear that its sole purpose was to show that the hypothesis involved not "miracles of transportation" or infinitesimal chances but reasonably probable chances. The quite inexcusable error in my figures to which he calls attention is not really material, nor is his conclusion that the calculation shows too many mammals for the known or inferential instances (I do not see that it does, by the way; but as the point is immaterial will pass it by). The main reason for introducing a calculation based upon a series of highly inexact approximations was to determine whether this method of transportation would afford a reasonably probable alternative to continental connection, in accounting for the presence of mammals on

[5] Manuscript received by the Editor 12 November, 1915.

certain oceanic islands, in which it appeared impossible to explain the characters of the mammal fauna upon any reasonable hypothesis involving continental union.

When it comes to applying the rafting theory to lower vertebrates and invertebrates, Dr. Barbour is quite right in insisting that one should have a special knowledge of the particular habits of each group in order to judge of possible or probable methods of its transportation. Because I lack that especial knowledge and field experience I avoided discussing it. I do not know how far the rafting theory is applicable to account for their distribution, and how far it may be more reasonably explained in other ways. But I do notice that Barbour appears to consider only the transportation of the adult animals, and says almost nothing about the possible transportation of their eggs. It is just because mammals do not lay eggs that their presence in oceanic islands seems peculiarly difficult to account for, save through former union with continents. Wallace, it will be remembered, for this reason regarded their presence as a dependable criterion of such union. Like most students of geographic distribution, I started from Wallace's views as a basis, and if I have modified them in an opposite direction from many of my confreres it is because I found that in certain particulars they did not fit the details of distribution, past and present, in the groups with which I am best acquainted. If mammals laid eggs, and especially if the eggs were numerous and of very small size, I should find it far easier—indeed quite too easy—to account for their presence on oceanic islands; the difficulty would be to account for their general absence. It is because they do not that I was compelled to discuss a rather complex hypothesis to account for their presence in Cuba, Madagascar and elsewhere. There are numerous other accidental means of transport which might be and have been invoked to account for dispersal of lower animals, but the ones I discussed were the only ones that, so far as I could see, would be possible for mammals. And for very large terrestrial mammals these seemed to me physically impossible. But no such mammals closely allied to continental ones are found on any oceanic islands;[6] those remotely related are derivable from the much smaller and more generalized ancestors which we find living in older epochs on the continents, and it is these small common ancestors whose dispersal must be accounted for.

It is the above considerations that underlay the remark to which Barbour takes exception on page 2. I do not think his objection is warranted, for while I do not question his judgment as to the improbability

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[6] There are certain exceptions to this statement—Malta, Cyprus, Crete and Celebes. These exceptions do appear to call for continental union.

of transporting certain types of adult reptiles, amphibians or invertebrates in the particular way that I have used to account for certain peculiarities in mammalian distribution, yet the transport of their eggs is a much less serious difficulty, and there are several other possible methods. These have been extensively discussed by others and I need not go into them. While it does not seem physically possible, for instance, that a mammal could survive being caught up by a hurricane or tornado, carried a long distance and dropped, I do not see any particular *impossibility* in the transport of young or eggs of amphibians or reptiles or invertebrates by such means. Indeed there is considerable evidence along this line on record. And if it be not a physical impossibility, then the element of geologic time *does* enter into the question of its probability.

So far as the West Indies are concerned, I do not at all suppose that no one of them has ever been united to any other. All are in lines of great disturbance and uplift; several are united by shallow platforms, and I see no reason at all against accepting Vaughan's view that Cuba and Haiti were probably united during the Tertiary, although now separated by a deep water channel. The mammalian evidence would accord well with that view, and recent discoveries in Porto Rico rather suggest that that island, as well as the Bahamas, may have been included in the union. But the mammalian evidence seems to me distinctly against any direct union with either North or South America in the middle or later Tertiary, and fairly conclusive against any such Pleistocene union. Indirect union, with an isolated Central American or Floridian island serves to raise problems of dispersal more difficult than any that it solves, because we have no past distributional evidence to go upon. It is too speculative to be worth discussion.

Dr. Barbour's criticisms deal, as he very cordially and generously insists, with a side issue of the main discussion in my paper. I may add that it is a side issue concerning which I have no desire to be dogmatic or positive.

My statement that the large ground birds are to-day peculiarly inhabitants of arid regions should have been more carefully qualified. It referred especially to the three large forms—the ostrich, rhea and emu—characteristic of the arid interior of the three southern continents. I had not meant to say that there was any such uniform association of habitat as the remark may seem to imply.

In reply to Doctor Allen's argument concerning Madagascar Cricetines, the following points may be considered:

1) All the Malagasy rodents belong to a peculiar group of Cricetines, the Nesomyinæ: that is to say, if the classification is a natural one they

are descended from a single stock, a single ancestral type, and as the group is peculiar to the island the inference would be that its differentiation took place after it reached the island and not before. The arrival of that type represents therefore one invasion and not nine.

2) The Cricetines are the older group, prevalent in Holarctica since the beginning of the Oligocene and presumably widely spread in the Ethiopian and Oriental regions during the Middle and later Tertiary. The Murines are a much later development and comparatively recent immigrants into the tropical Old World, where they have supplanted the older Cricetines more completely than in the less accessible tropical New World. The Cricetines have therefore had a much longer time than the Murines to reach Madagascar through accidental transportation; it is to be expected that the single stock which arrived should be a Cricetine.

3) The Malagasy lemuroids, Gregory has recently shown, all belong to a single group, distinct from any of the continental lemuroids, and may equally be supposed to represent a single invasion. But the wide differentiation indicates that this invasion must be a much earlier one than that of the Cricetines.

4) The Carnivora—all viverrines—are not so clearly derivable from a single stock, but they may be so (*Cryptoprocta,* although highly specialized, is fundamentally a Middle Tertiary viverrine). The date of arrival can hardly be much later than Oligocene, and certainly not earlier.

5) The insectivores—all Centetidæ—are likewise derived from a single stock, peculiar to the islands, its only continental relative being the Potamogalids. The diversity of the Malagasy Centetids indicates an early Tertiary invasion.

6) The pigmy hippopotamus must be a late arrival, for the Hippopotami were not evolved until the late Tertiary, and no adaptive radiation has occurred in Madagascar.

7) An Eocene land connection and subsequent isolation might account for the Lemurs and Centetids, but would not allow of land invasion by Viverrids, Cricetines or Hippopotami. We should expect also that at least some remains of the Eocene ungulates and creodonts would survive, since they were not displaced by higher types as on the mainland.

8) An Oligocene land connection with isolation before and after might explain Lemurs, Centetids and Viverrids, but not the Cricetine group and certainly not the Hippopotami, and would be difficult to reconcile with the absence of monkeys and of the primitive ruminants and proboscideans (all already in Africa in Lower Oligocene).

9) A Miocene or Pliocene land connection with isolation before and after would explain the Cricetines, and either the Viverrines (if early)

or the Hippopotamus (if late), but hardly both. It would be irreconcilable with the presence and diversity of the Lemurs and Centetids, the absence of monkeys and of the rest of the later Tertiary mammal fauna of Africa.

10) A land connection throughout the Tertiary would account for the presence of the few mammal types that have reached the island, but not for the complete absence of the very numerous groups of several successive faunas which are not present. The amount and character of the adaptive radiation among the half dozen stocks that are present indicates the absence of monkeys, ungulates, cats etc. in the past as well as in the present, as also that the half dozen different elements of the mammalian fauna were due to invasion by single types at several different epochs. The indicated epoch corresponds in each case to the time at which the geologic record indicates that their ancestral stocks were prevalent on the adjacent mainland.

11) Madagascar, it should be remembered, is an island of almost continental size and great geologic antiquity. It is not a transitory islet, such as Barbour cites in support of his contention that mammals behave strangely on oceanic islands. If a continental fauna once gained access to it there would be no reason for its extinction, nor opportunity for the expansive radiation of a few stocks. If Doctor Allen's explanation were correct, the relations of the fauna to the Ethiopian should be similar to those of Borneo or Sumatra to the Oriental mainland fauna, save for a wider amount of differentiation from the late Tertiary and Pleistocene invaders of the Ethiopian region. The briefest summary of its character, such as is given above, is enough to show how widely it differs from that type.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Vol. XXVII, pp. 17–22, pll. I–V

Editor, Edmund Otis Hovey

AN EXTINCT OCTODONT FROM THE ISLAND OF PORTO RICO WEST INDIES

BY

J. A. Allen

NEW YORK
PUBLISHED BY THE ACADEMY
25 January, 1916

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[ANNALS N. Y. ACAD. SCI., Vol. XXVII, pp. 17-22, Pll. I-V. 25 January, 1916]

AN EXTINCT OCTODONT FROM THE ISLAND OF PORTO RICO, WEST INDIES[1]

BY J. A. ALLEN

(*Presented in abstract before the Academy, 8 November, 1915*)

CONTENTS

INTRODUCTION

The mammal remains here described were taken from a cave near the center of the island of Porto Rico in excavations directed by Dr. Franz Boas, in charge of the anthropological division of the Natural History Survey of Porto Rico, now being carried on jointly by the New York Academy of Sciences and the American Museum of Natural History, in coöperation with the Government of Porto Rico. These remains have been kindly placed in my hands by Dr. Boas for determination. Aside from a few human bones, they consist almost wholly of the bones of a large rodent allied to *Plagiodontia*.[2] With them are a few bird bones, too imperfect for satisfactory identification. These have been referred to Mr. W. De W. Miller, Assistant Curator in Ornithology in the American Museum, who informs me that they represent, principally at least, a pigeon and a parrot, the latter probably referable to the genus *Amazona*.

In reply to my inquiries regarding the manner of occurrence of these

[1] Manuscript received by the Editor, 27 November, 1915.

[2] There is a single dorsal vertebra of a much larger animal, as yet not determined.

remains, Dr. Boas has kindly furnished me (*in litt.*) with the following details: "The remains were found in a heavy deposit of ashes in a cave in the Jobo district, between Utuado and Arecibo. In the same deposit was the burial of a child. A very large number of shells of crabs and of various kinds of snails were found. The deposit was undoubtedly artificial. I do not believe that it was purely an accumulation of kitchen refuse. It seems more likely that it was made for some other purpose. There is no indication of post-Columbian disturbance of the deposit, but I do not presume that it is more than a few hundred years old."

The mammal remains include nearly 400 pieces, representing nearly all parts of the skeleton, and all are apparently referable to a single species. They are for the most part fragmentary, but some of them are complete, there being entire bones of all the principal parts of the skeleton except the vertebræ and the feet. They are lightly coated with a gray ashy covering, easily removed with a soft brush, and have the appearance and general character of recent bones, having undergone no mineralization nor much discoloration. These remains may be listed as follows:

20 skulls, none of them quite complete, the occipital and parietal regions and the nasals being usually lacking, while many consist of only the middle portion of the skull.

150 mandibular rami, including a score or more in nearly perfect condition; in many the condylar portion is defective or wholly lacking.

15 scapulæ, including several nearly entire.

1 clavicle, the distal end wanting.

15 humeri, several complete and others nearly so.

30 ulnæ, mostly well preserved.

10 radii, mostly in good condition.

25 femora, some perfect, others nearly complete.

40 tibiæ, many in good condition.

5 fibulæ, mostly in fair condition.

1 sacrum, almost perfect.

50 ribs, many well preserved.

50 innominate bones, a few with the borders only slightly abraded, but the greater part are fragmentary.

Besides the above, there are several hundred fragments of little or no scientific value.

These remains indicate an animal about the size of *Capromys pilorides,* but with a broader and shorter skull, and a slenderer body and longer limbs. It differs widely in dentition from *Capromys,* in which respect it approaches *Plagiodontia,* as it does also in the size and shape of the skull. It is generically distinct from either, and may be described as follows:

Isolobodon[3] portoricensis gen. et sp. nov.

Type, No. 38409*a*, from the Cuerva de la Seïba, near Utuado, Porto Rico; coll. Dr. Franz Boas. The type skull has the nasals and entire upper dentition complete, but lacks part of one zygoma and the braincase posterior to the fronto-parietal suture.

Description

Skull.—The skull (Plate I, Figs. 3-8) closely resembles in outline and proportions that of *Plagiodontia,* being shorter and broader than the skull of *Capromys.* The most nearly complete skull of the series (No. 38409*b*), which lacks only the nasals, the occipital region and most of the teeth, when laid over F. Cuvier's outline figure of the skull of *Plagiodontia*[4] is found to be essentially of the same size and form. The lower jaw is of the same size, but differs somewhat in the form of the condylar portion, which, however, is not well shown in Cuvier's plate. The nasals are of nearly uniform breadth from base to tip, widening only slightly and uniformly from the base anteriorly.

The most nearly complete skull of the series is above the average in size, and is also evidently the skull of a very old individual. This skull affords the following measurements: front border of premaxillaries to occipital suture, 73 mm.; length of frontals on midline, 28; length of parietals on midline, 25; length of rostrum, 25; width of rostrum at anterior root of zygomata, 13; depth of rostrum at same point, 19; interorbital breadth, 23.4; zygomatic breadth, 48.5; greatest breadth of braincase (at posterior base of zygomata), 24; palatal length, 33.5; breadth of palate between premolars, 3; breadth of palate between last molars, 7, the toothrows being strongly convergent. The type skull, fully adult but smaller and evidently younger than No. 38409*b*, furnishes the following: Interorbital breadth, 22; length of frontals on midline, 25; length of nasals, 25; breadth of nasals at base, 8.2; breadth of nasals near front border, 9; length of maxillary toothrow (crown surface), 16.5; palatal length, 33.5; palatal breadth between premolars, 2.5; palatal breadth between last molars, 7.5; greatest breadth of skull (behind base of zygomata), 26.

The size of the lower jaw (Plate I, Figs. 1-2; Plate II, Figs. 1-4, 8-9) varies greatly in different specimens, apparently due mainly to age but perhaps partly to sex. Adult mandibular rami vary in total length (base of incisor to tip of angular process), from about 48 to 56 mm.; depth at

[3] ἴσος, equal; λοβός, lobe; ὀδών = ὀδούς tooth. In allusion to the equal lobes of the molar teeth.

[4] Ann. des Sci. Nat., ser. 2, VI, 1836, pl. 17, fig. 3.

m^1, 12.5 to 14.5; depth at coronoid process, 17 to 22; depth at condylar process, 18 to 24 mm.

The maxillary toothrow (crown surface) varies in length, in adults, from 15.5 to 17 mm.; the mandibular toothrow from 17.5 to 19 mm. The teeth evidently increase in size with age, not only in length and breadth but in height, becoming more hyposodont as well as larger in old adults, and the angles of the folds more prominent.

Dentition.—In *Capromys* the transverse axis of the molar teeth forms a right angle with the axis of the toothrow; in *Plagiodontia* the transverse axis of the molars is highly oblique to the axis of the toothrow (Plate II, Fig. 10); in *Isolobodon* the obliquity is about 45° [5]. The incisors are weak, nearly flat on the outer face, without grooves, and rounded on the inner face. Their color, still well preserved, is pale yellow.

The molariform teeth in *Isolobodon* (Plate II, Figs. 5-7) resemble those of *Plagiodontia* in size and shape, in the obliquity of their insertion, and in the number of folds on the outer and inner borders, but not at all in the enamel pattern. They are thus modeled on a basis common to both types, and both thus differ widely from the teeth of *Capromys.* In *Plagiodontia* the cement area of the crown surface of each tooth consists of three transverse divisions, united and continuous, thus constituting a single sigmoid area, deeply cut by the infolding of the enamel border. In *Isolobodon* the cement of the crown surface of each molar forms two transverse, nearly equal oval lakes, entirely separate and encircled by an enamel border. The enamel walls of the two loops touch each other by a slight point of contact near the outer border of the upper teeth and the inner border of the lower teeth. The enamel pattern of the lower molars differs from that of the upper through a deep indentation of the anterior enamel lake by the infolding of the enamel border on the inner side of the front third of the tooth.

All of the molars have each two vertical ribs or folds on both the external and internal borders, but the upper premolar differs from the molars in having three external and two internal. The lower molars have each three external and two internal folds. The lower premolar has three folds on each side, but the anterior fold is greatly reduced in depth, and thus gives rise to a small trefoil termination to the crown surface of the front border of the tooth.

The upper teeth successively decrease in size from the premolar to m^3,

[5] If the upper molar series is correctly represented in Cuvier's plate, the maxillary teeth in *Plagiodontia* have the transverse axis of the teeth nearly coincident with the longitudinal axis of the toothrow, while in the mandibular series the angle is only about 45°, as in *Isolobodon.* I cannot resist the impression that the obliquity of the maxillary teeth is highly exaggerated in Cuvier's drawing.

which is only about half the size of m^1. The lower teeth are of nearly equal size, except that the premolar is narrower than the molars, with the anterior third terminating in a narrow projecting terminal angle, and is thus slightly trilobed on the anterior face.

Scapula.—The scapula resembles that of *Capromys pilorides*,[6] but is longer and narrower, in correlation with the more slender form of the whole animal (the skull excepted) in *Isolobodon.* It has a total length of 45 mm., and a breadth at the middle of 24.5 mm. The free end of the spine (acromian process) is nearly as long as the attached portion. (For further details see Plate III, Figs. 1-4.)

Clavicle.—A single fragment, if identifiable as this bone, is much longer and slenderer than the corresponding bone in *Capromys pilorides.* It lacks both epiphyses, but still has a length of 26 mm.

Humerus.—Greatest length, 45 mm.; diameter of proximal end, 11.5 × 9.5; transverse diameter of distal end, 11.5 × 5 mm. The supratrochlear foramen is of medium size and the deltoid ridge is rather strongly developed (Plate III, Figs. 5-7).

Ulna and radius.—Length of ulna without distal epiphysis, 57 mm. Olecranon process is strongly developed, forming about 1/6th of the length of the bone. All of the radii lack the distal epiphyses. The length, minus this portion, is about 46 mm. (Plate III, Figs. 8-14).

Sacrum.—The single sacrum in the collection is fortunately well preserved. It consists of four perfectly ankylosed vertebræ and presents nothing of noteworthy importance. It has a length of 51 mm.; breadth at the proximal end, 31 mm., at the distal end, 15 mm. It is represented in three views, all natural size, in Plate IV, Figs. 4-6.

Pelvic girdle.—Of the many innominate bones in the collection all are to some extent abraded on their epiphysial borders, but several of them are sufficiently complete to show all of the essential characters. The one chosen for representation in Plate IV, Figs. 1-3, of which three views are given, natural size, indicate its general character. The main axis is nearly straight, not slightly convex dorsally, as in *Capromys pilorides.* The usual tuberosities are strongly developed. The total length is about 81 mm., of which the ilium constitutes about two thirds. Greatest breadth of ilium, 24 mm., of the ischium and pubis, opposite the middle of the thyroid foramen, respectively 9 and 6 mm. The thyroid foramen is large, oval in outline, nearly twice as long as broad, the length in adult specimens being about 20 mm.

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[6] The only pertinent skeletal material available for comparison with that of *Isolobodon* is a ligamental, badly diseased menagerie skeleton of *Capromys pilorides,* to which my comparisons are here necessarily restricted.

Tibia and fibula.—Most of the tibiæ lack the distal epiphysis. The greatest length of a complete adult tibia is about 64 mm. The digital fossa is very deep, and there is a slight indication of a third trochanter in old individuals (Plate V, Figs. 1-4). The fibulæ are all except one more or less fragmentary, lacking the distal epiphysis. The single complete bone has a length of 44 mm. (Plate V, Figs. 5-9). The bones of the hind limb in *Capromys pilorides* are about one fifth shorter and much thicker than in *Isolobodon.*

Summary

Isolobodon, like *Plagiodontia,* is evidently of recent extinction. In the case of *Plagiodontia,* the only extant specimen, so far as known to me, is the type of the species in the Paris Museum of Natural History, described by F. Cuvier in 1836, to which account all the subsequent references revert. Cuvier had apparently only a single specimen, sent to him from Santo Domingo by M. Ricord, from whom Cuvier's brief account of its habits was doubtless derived. It is mentioned as being nocturnal and frugivorous, its flesh as very good to eat, and that for this reason "les Haitiens, qui en sont très friands, les recherchent si soigneusement, qu'ils ont fini par rendre ces animaux très rare." In all probability it was soon after completely exterminated. It is also probable that *Isolobodon* had already become extinct in the neighboring island of Porto Rico, doubtless from a similar cause, and perhaps not long prior to the discovery of the island by Europeans. At least the fresh condition of its remains found in Seiba Cave seems to imply recent extinction.

PLATE I

SKULL AND LOWER JAW OF **Isolobodon portoricensis** gen. et sp. nov.

FIGS. 1 and 2.—Left mandibular ramus, outer and inner views. (Natural size.)
FIGS. 3–5.—Three views of the type skull. (Natural size.)
FIGS. 6–8.—Three views of a paratype skull, rather older and larger than the type skull. (Natural size.)


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PLATE II

LOWER JAW AND DENTITION OF Isolobodon portoricensis gen. et sp. nov.

FIGS. 1–4.—Right mandibular ramus of a young adult. (Natural size.)

FIG. 5.—Lower toothrow, left ramus. From same specimen as Pl. I, Figs. 1 and 2. (Twice natural size.)

FIG. 6.—Lower toothrow, right ramus, of a young adult. From same specimen as Figs. 1–4. (Twice natural size.)

FIG. 7.—Right maxillary toothrow. (Twice natural size.)

FIGS. 8 and 9.—Upper and lower views of the left mandibular ramus shown in Pl. I, Figs. 1 and 2. (Natural size.)

FIG. 10.—Upper and lower dentition of *Plagiodontia ædium* F. Cuvier, for comparison with that of *Isolobodon*. After F. Cuvier, Ann. des Sci. nat., ser. 2, Vol. VI, 1836, pl. xvii, figs. 4 and 5. (Natural size.)

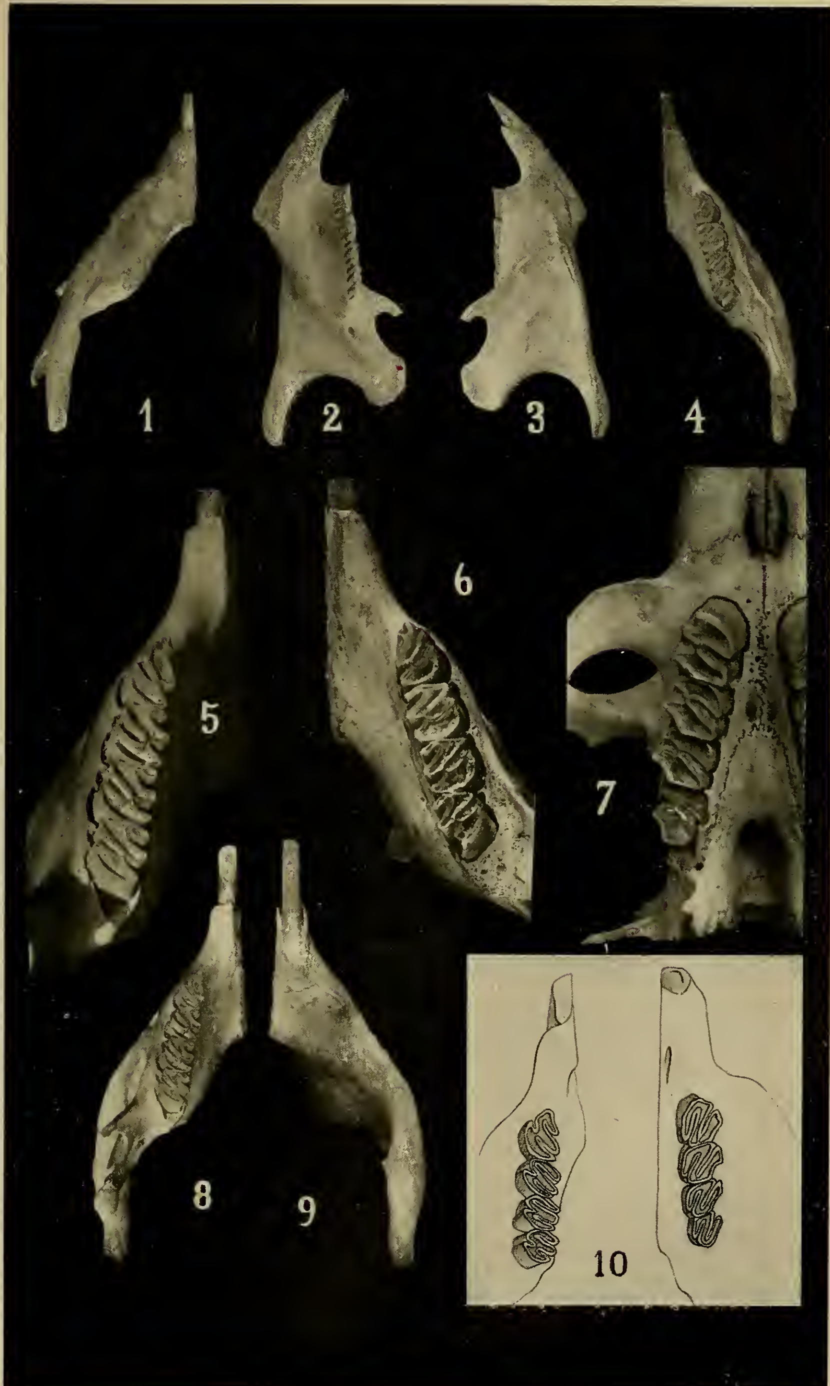
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PLATE III

SCAPULA, HUMERUS, ULNA AND RADIUS OF Isolobodon portoricensis gen. et sp. nov.

FIGS. 1–4.—Three views of the scapula and its articular face. (Natural size.)
FIGS. 5–7.—Three views of the humerus. (Natural size.)
FIGS. 8 and 9.—Two views of the ulna. (Natural size.)
FIGS. 10–12.—Three views of the radius. (Natural size.)
FIGS. 13 and 14.—Proximal and distal articular surfaces of the radius. (Natural size.)

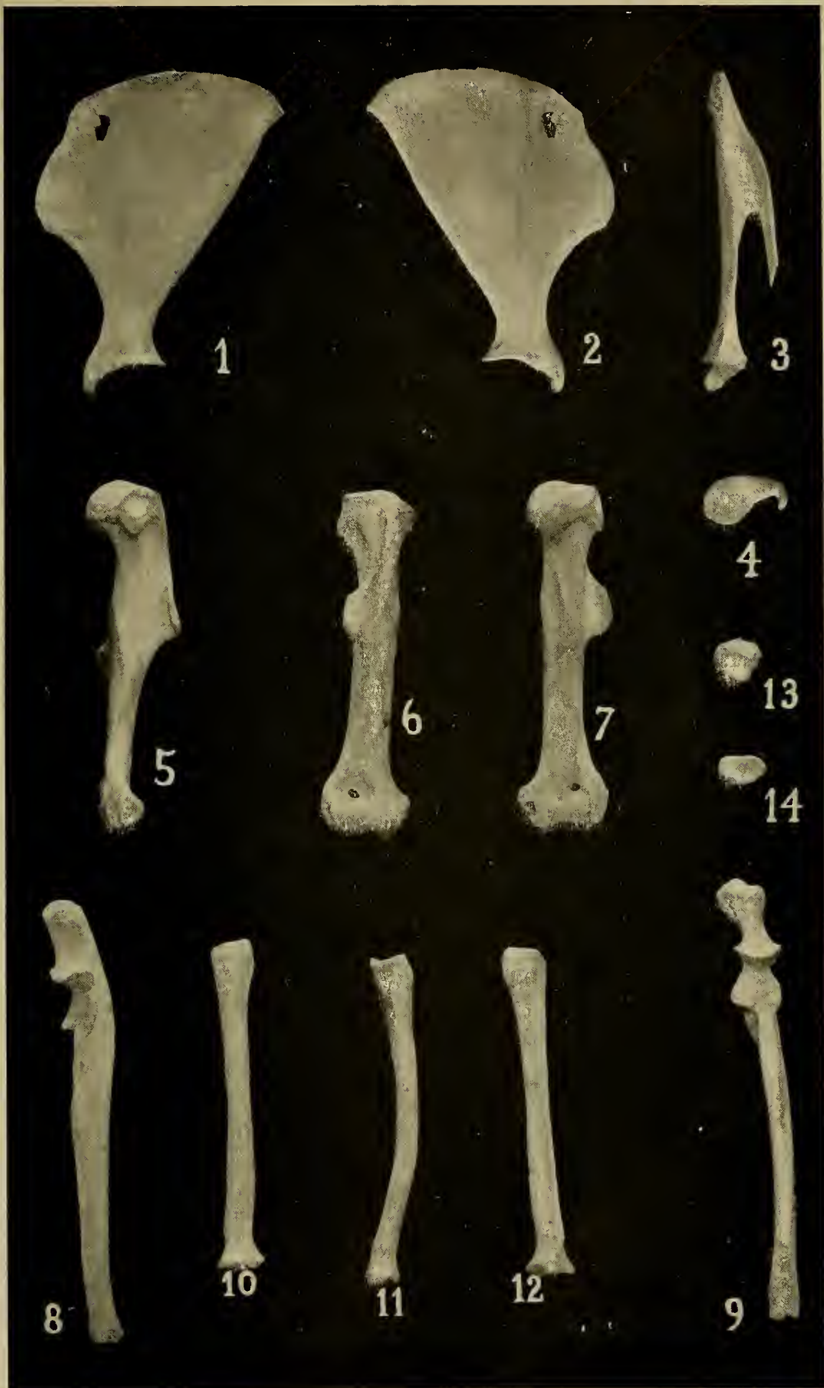
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PLATE IV

SACRUM OF *Isolobodon portoricensis* gen. et sp. nov.

FIGS. 1–3.—Three views of a right innominate bone. (Natural size.)
FIGS. 4–6.—Three views of the sacrum. (Natural size.)


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PLATE V

FEMUR AND TIBIA OF Isolobodon portoricensis gen. et sp. nov.

Figs. 1–3.—Three views of a right femur. (Natural size.)
Fig. 4.—Distal articular surface of the same femur. (Natural size.)
Figs. 5–7.—Three views of a right tibia. (Natural size.)
Figs. 8 and 9.—Views of the articular faces of the same tibia. (Natural size.)


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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Vol. XXVII, pp. 23-29

Editor, Edmund Otis Hovey

NEW SIRENIAN FROM THE TERTIARY OF PORTO RICO, WEST INDIES

BY

W. D. Matthew

NEW YORK

PUBLISHED BY THE ACADEMY

28 January, 1916

[ANNALS N. Y. ACAD. SCI., Vol. XXVII, pp. 23-29. 28 January, 1916]

NEW SIRENIAN FROM THE TERTIARY OF PORTO RICO, WEST INDIES[1]

BY W. D. MATTHEW

(*Presented before the Academy, 8 November, 1915*)

CONTENTS

INTRODUCTION

Two specimens of fossil mammals were secured by Dr. Chester A. Reeds from the Tertiary limestones of Porto Rico while on the natural history survey of that island undertaken by the Academy. One consists of a lower jaw and two vertebræ, the other of a few incomplete ribs. The second specimen is probably sirenian but not further identifiable. The lower jaw, however, is nearly complete, with the molar teeth preserved and alveoli of the premolars, and is of considerable interest.

Tertiary mammals have been practically unknown from the West Indies. The only one recorded in scientific literature, so far as I know, is represented by the skull and jaws from so-called Eocene of Jamaica, described many years ago by Owen under the name of *Prorastomus sirenoides.* It is also a sirenian, of a more primitive and generalized type. In the March, 1914, number of the magazine "Revista de las Antillas," Senor Narciso Rabell Cabrero has published photographs of two mammal bones from the Porto Rican Tertiary, a scapula and axis, and discussed their possible affinities. He did not compare them with Sirenia, and naturally found the relationship to terrestrial mammals very perplexing. The scapula is characteristically sirenian, having the peculiar curvature and backward extension of the blade clearly indicated and agreeing in

[1] Manuscript received by the Editor 27 November, 1915.

other features with the older stages of the Halicoridæ. The axis agrees with the same types, comparing with *Halitherium*, but is less certainly identifiable.

The lower jaw found by Dr. Reeds is clearly distinct from *Prorastomus* and from the modern manatee (*Manatus* = *Trichechus*), and appears to be related to *Halitherium* of the European Oligocene. Unfortunately the front of the jaw is missing, so that the identification is in some degree provisional; but the form, proportions and spacing of the teeth preserved or indicated by their alveoli agrees with this genus, as does also the form of the lower jaw. It is with some hesitation that I refer it to an Old World genus, but the known range of the manatee in Africa and tropical America, with fossil representatives in Belgium as well as along the Atlantic coast of the United States, makes it quite reasonable to believe that *Halitherium* also ranged on both sides of the Atlantic in Tertiary times. Its modern descendants, the Dugongs, are found in the Indian Ocean and Red Sea.

The lower jaw here described is about the size of a manatee jaw, and with the same great depth of angle, high condyle, heavy coronoid process, deep pterygoid fossæ. It is much deeper and heavier posteriorly than in *Prorastomus* and somewhat deeper under the molars. Three molars are preserved. Although badly worn and the inner sides much damaged by weathering, it is evident that they were rather short-crowned teeth of the usual primitive sirenian pattern of five robust cusps arranged in two cross-crests and a small heel. The last molar was apparently considerably longer than the second, with a much more distinct heel supported on a small median posterior root which the anterior molars lack. The first molar appears considerably smaller than the second, but this is chiefly due to its being more worn. Of the differentiation of m_3 from m_1 and m_2 there is no question. The premolars are indicated by alveoli. P_4 (more probably dp_4) was two-rooted, much smaller than m_1. P_3 has a single oval root, with a diastema behind it equal to its own greater diameter. P_2 is doubtfully indicated by an obscure round alveolus with a diastema separating it from p_3.

In front of this the jaw is broken off obliquely and it is impossible to say what it was like. So far as they go, the characters agree with *Halitherium schinzi*, save for the somewhat shorter and deeper posterior portion of the jaw, smaller molars, and greater reduction of the premolars. From *Manatus* the jaw differs in the reduction of the premolars and differentiation of the last molar; from *Prorastomus* in the much greater depth of the jaw posteriorly, reduction of the premolars and larger size of the molars.

FIG. 1.—? *Halitherium antillense, lower jaw, left ramus, type specimen, one-half natural size*

External view, symphyseal region missing. Tertiary shales near Juana Diaz, Porto Rico, found by C. A. Reeds, 1915.

Description of Species

? *Halitherium antillense* sp. nov.

Type: a lower jaw lacking symphyseal region and anterior teeth; the molars damaged on inner side; a middle cervical and the first dorsal vertebra associated, neither complete.

Type locality: Shale bluff, west bank Jacagnas River, 1 km. north, 1 km. west of Juana Diaz, Porto Rico.

Horizon: Tertiary calcareous shales of uncertain age.

Collector: Chester A. Reeds, N. Y. Academy of Sciences-Porto Rico Survey, July 1, 1915.

Diagnosis.—Size and proportions of jaw in accord with *H. schinzi,* premolars more reduced, the third (fourth of *Lepsius*) having but one root and the roots of the fourth (milk-molar, dp_4) indicating a smaller tooth than the corresponding tooth in *H. schinzi*. It agrees better with Abel's diagnosis (Abel, 1904, p. 16, 25) of *H. christoli* Fitz., from the upper marine Molasse of Linz (Middle Miocene), but Fitzinger's (Fitzinger, 1842) figures of the jaw in this species are not accessible.

Probable Affinities.—Accepting provisionally the reference of the Porto Rico sirenian to *Halitherium*, it may be of interest to note where it stands in the evolutionary history of the Sirenians.

It is generally accepted at present that this group is descended from a common stock with the Proboscidea—that is to say, they are derived from terrestrial ungulates with short five-toed plantigrade feet, a complete series of teeth, bunodont molars, four or five cusped, the posterior premolars partly molariform, the anterior ones simple, canines not notably enlarged, but a tendency to enlargement of a pair of upper and lower incisors—and a variety of other characters which I need not notice. *Mœritherium*, of the Upper Eocene and Lower Oligocene of Egypt, stands not very far from this common stock; but whether or not it be really ancestral to the Proboscidea it has gone a short distance in that direction, the limbs being somewhat long and straight and the teeth and skull approaching in some degree the Proboscidean specialties more clearly shown in *Palæomastodon* of the Egyptian Oligocene.

Prorastomus, on the other hand, may be taken as representing the primitive Sirenian. Unfortunately we do not know its skeleton characters. But being found in a marine limestone it probably was already adapted to aquatic life. The long narrow skull, rather slender jaws, teeth conforming to the primitive type indicated and not widely different from those of *Mœritherium*, all point to its ancestral position.

From this primary stock we find three or four diverse lines of specialization. In the Manatee the front teeth disappear and the cheek teeth all become molariform and appear to increase in number, pushing upward and forward in the jaw to replace those lost by wear. This increase in number of the cheek teeth is supposed to be due to reduplication of the molars from behind, a fourth, fifth, sixth true molar etc. appearing *de novo* (Thomas and Lydekker, 1897).

In the Dugongs, on the other hand, one pair of upper incisor teeth is retained and enlarged into tusks, while the cheek teeth are progressively reduced in number, the premolars becoming smaller and simpler and the anterior ones disappearing, while there is no tendency to increase in number of the true molars. The skull in both Manatee and Dugong is much shortened and widened, the jaws deepened and the front of muzzle and jaw bent downwards and covered with horny plates for triturating the food. Various other specializations occur in the skull, carried considerably further in the Dugong.

A third line, closely related to the Dugong in most of its skull structure, but lacking the tusks, and with the reduction of the cheek teeth carried to complete disappearance, is represented by the recently extinct *Rhytina* of the North Pacific.

A fourth and very distinct line is represented by an imperfectly known genus *Desmostylus* found in the Miocene of Japan, California and Ore-

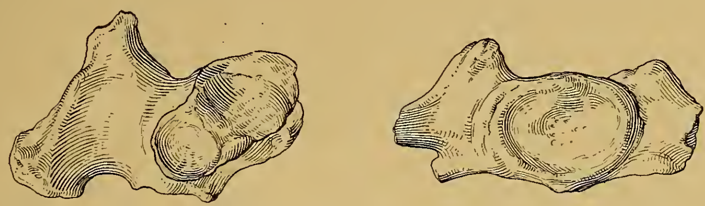

FIG. 2.—? *Halitherium antillense, parts of cervical (right) and anterior dorsal (left) vertebræ of type specimen*

Posterior views, half natural size.

gon. In this the skull retains more of its primitive proportions, while the tusks are large in both upper and lower jaws and the cheek teeth become hypsodont or high-crowned and of a very curious pattern.

Halitherium is generally accepted as an ancestral Dugong. *Eotherium* Owen, *Eosiren* Andrews, *Protosiren* Abel, *Archæosiren* Abel, all from the Eocene of Egypt, are a closely related group of genera, all but the first due to the activity of recent investigators in the Fayûm faunas, especially Andrews and Abel. They represent collectively a primitive stage in the Dugong line.

Place of Origin of the Dugongs

As the Manatees have not been found outside the Atlantic Basin, it is commonly assumed that they originated there or else migrated from the Tertiary Mediterranean Basin. The oldest fossil Dugongs being found in Egypt and Italy, later stages in Germany, France and Belgium, the modern forms in the Red Sea and Indian Ocean, it has been assumed that they originated in the Mediterranean Basin, found their way to the north European shores and in the opposite direction into the Indian Ocean, and thence perhaps finally to the North Pacific, but never reached the western coasts of the Atlantic.

The discovery here presented would seem to show that the distribution of primitive Dugongs in the North Atlantic was wider than was supposed. Why they disappeared in this region, while the rival group of Manatees survived is an interesting question; but the evidence as to the distribution and range of the Sirenia during the Tertiary is so scanty and incomplete that any further speculations are scarcely worth while.

Molar-premolar Formula in Sirenians

The molar-premolar formula in the Sirenia is difficult to state correctly, partly because of certain peculiarities in the premolar replacement, partly the doubtful interpretation of alveoli where the teeth themselves are not known. So far as the Manatees are concerned, I have accepted the interpretation placed by Thomas and Lydekker upon the cheek teeth, involving an actual increase in the number from the primitive formula of four premolars and three molars which pretty certainly characterized the ancestors of all placental mammals. This increase in number of molars would appear to be attained by extension of the dental lamina posteriorly and budding from the tooth germ of the third molar, thus continuing the process by which the third is derived from the second and the second from the first. That such an increase, whether by this or other means, does occur normally in the number of true molars in certain other placental phyla, appears beyond question. *Otocyon, Centetes, Myrmecobius* and various Cetaceans may serve as illustrations. The abnormal occurrence of an extra molar or premolar in the series is not a rare occurrence among other placental mammals; this is usually ascribed to reduplication.

It is by no means clear that there is any such increase in the number of either premolars or true molars in any of the other Sirenians living or extinct. Andrews ascribes four lower molars and four premolars to *Eosiren,* and Lepsius gives the formulas as: $i\frac{3}{3}\ c\frac{1}{1}\ p\frac{4}{4}\ m\frac{4}{4}$ in *Prorastomus;* $i\frac{1}{(3)}\ c\frac{1}{1}\ p\frac{3}{4}\ m\frac{4}{4}$ in *Halitherium;* $i\frac{2}{3}\ c\frac{0}{1}\ p\frac{1-2}{2-3}\ m\frac{4}{4}$ in *Halicore.* This would seem to indicate four true molars as the normal number in this family. Abel, however, has shown (Abel, 1906) that the fourth milk molar in the Halicoridæ is retained exceptionally late in life, and sometimes intercalated between the last successional tooth and the first true molar. He accounts in this way for the apparent series of eight postcanine teeth in the lower jaw of *Eosiren, Halitherium* and the later Halicoridæ without finding it necessary to suppose the addition of a molar from behind to the usual placental series. Possibly the eight postcanine teeth of *Prorastomus* are to be explained in this way; but the interpretation of the alveoli in the jaw in this and other genera is apparently somewhat doubtful. Pending the publication of Abel's final conclusions, it seems best to accept his present views provisionally, as I have done in the above diagnosis and discussion of affinities of *H. antillense*. The number of true molars is considered as unchanged from the primitive series of three, and the alveoli of the tooth preceding them are considered as of milk-molar four, although there is no proof that this tooth had a successor in *Halitherium*.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXVII, pp. 31-38

Editor, Edmund Otis Hovey

THEORIES OF THE ORIGIN OF BIRDS

BY

William K. Gregory

NEW YORK
PUBLISHED BY THE ACADEMY
4 May, 1916

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. XXVII, pp. 31-38. 4 May, 1916]

THEORIES OF THE ORIGIN OF BIRDS[1]

By William K. Gregory

(Presented before the Academy, 13 December, 1915, in connection with Mr. C. W. Beebe's paper on "A Tetrapteryx Stage in the Ancestry of Birds")

Comparative anatomists of the nineteenth century demonstrated that birds, in the entire ground plan of their brain, skeleton, reproductive organs and all other structures, as well as in their mode of development, are "glorified Reptiles," or "feathered saurians." In this instance the unanimous findings of comparative anatomy may be regarded as practically decisive.

But while all authorities agree that the assumed very remote ancestors of birds that lived in the Carboniferous and Permian periods of the earth's history were very probably scaly, lizard-like reptiles, there is no such unanimity regarding the structure and habits of the more immediate ancestors of birds, during the ages when scales were gradually transforming into feathers and the art of flying was still in its earliest stages. Professor Osborn, in 1900, after reviewing the evidence for the well-known view that birds and dinosaurs had been derived from a common ancestral stock that lived during the Permian period, said:[2] "In the origin of the birds we have to imagine, first, a terrestrial stage, in which bipedal was gradually substituted for quadrupedal progression; it would appear probable that the bipedal progression was first acquired during a terrestrial stage because the foot of birds is primarily a walking, and not a climbing, organ; second, a cursorial bipedal or, more probably, an arboreal stage, in which both fore limb and tail enjoyed a change of function contemporaneous with the acquisition of feathers."

In 1906 Mr. W. P. Pycraft, of the British Museum, argued that[3] in the stage preceding *Archæopteryx* (the oldest known fossil bird, of the Jurassic period) the ancestral birds probably lived in the trees, leaping from branch to branch and from tree to tree. "In these movements," he

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[1] Manuscript received by the Editor 24 February, 1916.

[2] "Reconsideration of the Evidence for a Common Dinosaur-Avian Stem in the Permian," The American Naturalist, Vol. XXXIV, No. 406. 1900.

[3] "The Origin of Birds," Knowledge and Scientific News. September, 1906, pp. 531-532.

continues, "we may reasonably suppose the fore limbs were used for grasping at the end of the leap. The use of the fore limb for this work would naturally throw more work upon the inner digits—1-3—so that the work of selection would rapidly tend to the increased development of these, and the gradual decrease of the two outer and now useless members. Correlated with this trend in the evolution, the axillary membrane—the skin between the inner border of the arm and the body—became drawn out into a fold, while a similar fold came to extend from the shoulder to the wrist, as the fore limb, in adaptation to this new function, became more and more flexed. While the fingers, upon which safety now depended, were increasing in length, and growing more and more efficient, they were, at the same time, losing the power of lateral extension and becoming more and more flexed upon the fore-arm. And the growth in this direction was probably accompanied by the development of connective tissue and membrane along the hinder, post-axial border of the whole limb, tending to increase the breadth of the limb when extended preparatory to parachuting through space from one tree to another, long claws being used to effect a hold at the end of the leap.

"The hind limbs, though to a less extent, were also affected by the leaping motion, resulting in the reduction of the toes to four, and the lengthening and approximation of the metatarsals 2-4 to form a 'cannon' bone.

"The body clothing at this time was probably scale-like, the scales being of relatively large size and probably having a medium ridge, or keel, recalling the keeled scales of many living reptiles. Those covering the incipient wing, growing longer, would still retain their original overlapping arrangement, and hence those along the hinder border of the wing would, in their arrangement, simulate in appearance and function the quill feathers of their later descendants. As by selection their length increased, so also they probably became fimbriated and more and more efficient in the work of carrying the body through space.

"There is less of imagination than might be supposed in this attempt at reconstructing the primitive feather, inasmuch as there is a stage in the development of the highly complex feather of to-day which may well represent the first stage in this process of evolution. Creatures such as are here conjured up would bear a somewhat close resemblance to *Archæopteryx,* and it is contended that the discovery of earlier phases of avian development, phases preceding *Archæopteryx,* will show that this forecast was well founded. But in *Archæopteryx,* it is to be noted, the feathers differ in no way from the most perfectly developed feathers known to us."

Mr. Pycraft summed up this theory in his restoration entitled "One of the 'Pro-Aves.'" This hypothetical animal, as thus represented, stands about half way between a normal lizard-like reptile on the one hand and *Archæopteryx* on the other. It is represented as volplaning down from the trees, with arms outstretched. It is covered with scales, which on the back of the arm and sides of the tail have begun to lengthen out and transform into feathers.

The next year (1907) Baron Francis Nopcsa, in the Proceedings of the Zoölogical Society of London,[4] after reviewing the many resemblances between birds and running dinosaurs and showing that birds both in their mode of flight and in their limb structure differ in many important respects from bats, flying squirrels and other primarily tree-living animals that are provided with webs of skin for volplaning, came to the following conclusions:

"If we, after these preliminaries, now suppose that Birds, before attaining the *Archæopteryx*-state, originated from quadrupedal arboreal animals and only after having learnt to fly became bipedal, it is difficult to understand why they in general show Dinosaurian affinities, why they did not use both hind and fore limbs to the same extent for flight as they would have done for arboreal locomotion, why the bones of the pectoral region and of the wings show more primitive traces than the hind parts of the body, and why they did not, like all other quadrupedal flying animals, develop a patagium; whereas, if we consider that in *Archæopteryx* the anterior extremities, though bearing the most important ectodermal pinions, are less modified than the posterior extremities, which are already perfectly bird-like, and if we then suppose that Birds originated from bipedal Dinosaur-like Reptiles, it is easy to understand what induced the Birds to attain an *Archæopteryx*-like stage of evolution, for at first a certain amount of bipedal, and only afterwards a volant, modification would be required.

"While we can safely state that a bipedal animal never could or did develop a patagium without giving up bipedalism, this cannot be said of feather-bearing forms, for we may quite well suppose that *birds originated from bipedal long-tailed cursorial reptiles which during running oared along in the air by flapping their free anterior extremities.* . . . A double running and flapping action would—somewhat in accordance with Pycraft's views on this subject—subsequently easily lead to an enlargement of the posterior marginal scales of the antibrachium, and at the same time produce a certain amount of bipedal specialization.

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[4] "Ideas on the Origin of Flight." Proceedings of the Zoölogical Society of London, June 12, 1907.

"By gradually increasing in size, the enlarged but perhaps still horny hypothetical scales of the antibrachial margin would in time enable the yet carnivorous and cursorial ancestor of Birds to take long strides or leaps, much in the manner of a domesticated Goose or of a Stork when starting, and ultimately develop to actual feathers; this epidermic cover would also raise the temperature of the body, and thus help to increase the mental and bodily activity of these rapacious forms."

In 1913 Doctor Robert Broom described the skeleton of a small fossil reptile from the Upper Triassic beds of South Africa, which he named *Euparkeria capensis*. This animal, the type of which is in this museum, belonged to an ancient group of reptiles called "Pseudosuchia," some of which are found in the Triassic of Connecticut and others in the Upper Triassic of Scotland, Germany and South Africa. This group is of exceptional interest to palæontologists because of the largely primitive character of certain of its genera, which show marked evidences of affinity with such diverse later groups as Dinosaurs, Pterosaurs and Crocodilians. In discussing the affinities of this group Dr. Broom[5] said:

"There is still another group to which some Pseudosuchian has probably been ancestral, namely, the Birds. For a time one or other of the Dinosaurs was regarded as near the avian ancestor. The resemblance of the hind limb and pelvis seemed to make this extremely probable, and Huxley, Marsh, Cope, and others have all favored this view. Others, however, were more impressed by the apparently avian characters in the skeleton of the Pterodactyls, and especially in the striking avian appearances in the brain, and have argued in favor of a close affinity between the Birds and the Pterodactyls. Osborn, while recognizing the affinities to both groups, and especially to the Dinosaurs, believed that the Birds and the Dinosaurs had a common ancestor, probably in the Permian. Seven years ago, when describing the skeletogenesis of the Ostrich, I argued that the bird had come from a group immediately ancestral to the Theropodous Dinosaurs. The Pseudosuchia, now that it is better known, proves to be just such a group as is required. In those points where we find the Dinosaur too specialized we see the Pseudosuchian still primitive enough. The bird pelvis has probably developed from a type like that of *Ornithosuchus* by the pubis turning further back and the symphysis becoming lost. Whether the union of the metatarsals is a primary or a secondary character is a debatable point. The question is really whether the bird ancestor was a hopping bipedal animal before it flew, or if it only hopped after the wing had become specialized. I am

[5] Proc. Zoöl. Soc., 1913, pp. 631-632.

strongly of the opinion that it was a hopping animal first, and that the metatarsus became strengthened to support the weight of the body entirely borne by the hind feet. It is easy to understand a hopping animal taking to an arboreal life and ultimately developing a wing out of a four-toed hand, while it seems unlikely that the hind foot could ever have developed by arboreal habits. It is interesting to note that while the ancestor of the Pterodactyls had four toes in the manus, there is very clear evidence from the skeletogenesis of the bird that the latter also had a four-toed ancestor.

"A Pseudosuchian which through a bipedal habit had developed a strengthened ankle-joint and a firm metatarsus, and had lost the 5th digit from the manus would meet all the requirements of the avian ancestor."

The theory that the immediate ancestors of birds were arboreal animals has also been supported by Professor Abel,[6] of Vienna, who maintained that the birds and carnivorous dinosaurs arose from a common arboreal, ancestral group with climbing feet. The carnivorous dinosaurs soon reverted to terrestrial habits, while the birds, remaining arboreal, only returned to terrestrial life long after the acquisition of flight. The cleft between birds and carnivorous dinosaurs runs back perhaps to the beginning of the Trias. Professor Abel's conclusions rest partly on the facts that both the hands and the feet of the smaller dinosaurs show marked resemblances to those of the arboreal bird *Archæopteryx.*

Mr. D. M. S. Watson,[7] on the other hand, holds that the backwardly directed first toe of some of the earliest dinosaurs was not a perching adaptation, but served as a strut, or prop, for the support of an animal in the early stages of walking upright.

Quite recently Professor S. W. Williston[8] has expressed the belief (*in litteris*) that the consolidation of the instep bones in the oldest birds was an adaptation to digitigradism, or the habit of raising the body upon the toes, and that flight originated by leaping from below upward, not by gliding downward.

Still more recently Mr. C. W. Beebe, of the New York Zoölogical Park, has made certain discoveries which lend additional evidence for the view that the immediate ancestors of the birds were arboreal animals. In a paper entitled "A Tetrapteryx Stage in the Ancestry of Birds"[9] Mr.

[6] Grundzüge der Paläobiologie der Wirbeltiere. Stuttgart, 1912.

[7] "The Cheirotherium," Geol. Mag., Decade VI, Vol. I, No. 603, September, 1914, pp. 395-398.

[8] "Trimerorhachis, a Permian Temnospondyl Amphibian," Journ. Geol., Vol. XXIII, No. 3, April-May, 1915.

[9] Zoologica, Scientific Contributions of the New York Zoölogical Society, Vol. II, No. 2, November, 1915.

Beebe found that in the young of various species of doves, pigeons, jacanas and owls there is a reduced pelvic wing, consisting of a row of degenerate flight feathers and a second overlapping row of "coverts," all stretched upon the patagium, or skin-fold, behind the femur. Owing to the lateness of the season, it was impossible at this time to extend further his observations on the "pelvic wing" of birds; but he states that "judging merely from the pterylosis of the adult, many species of Coraciiformes, Scansores and Piciformes should show most interesting developments of this tract in the young birds." Mr. Beebe was naturally delighted to find that in the Berlin specimen of *Archæopteryx* there were some strongly marked impressions of feathers on both sides of the tibia and of still larger feathers lying between the pelvis and the bent back head, which he interprets as evidence of the "pelvic wing" in this oldest known bird. Partly from these data Mr. Beebe and Mr. Dwight Franklin have made their series of restorations to illustrate the evolution of birds from a "tetrapteryx stage," with four wings and a long segmental tail, to the modernized two-winged stage, with a normal fan-tail.

Thus Mr. Beebe, along with Pycraft, Abel and others, conceives the immediate ancestors of birds as arboreal animals with the habit of scaling downwards through the air after the fashion of flying squirrels; to this theory his discovery of a vestigial pelvic wing in modern birds lends obvious support.

For some years past the present writer has taken special interest in the problem of the origin of birds, partly for the reason that the subject forms one of the major problems in the Columbia University graduate course on the evolution of the vertebrates. Each year we hold a seminar on this subject, in which the various theories of the origin of the birds are duly advocated by graduate students, and the rival claims of the dinosaurs and other reptilian groups to close kinship with the birds are considered. From this annual review arises the impression that from the clash of conflicting hypotheses the following approximation to the facts may, from present evidence, be provisionally made out:

Far back in the Carboniferous ages the remote common ancestors of birds, dinosaurs, pterosaurs and other reptilian groups were very primitive lizard-like reptiles with extremely small brains, comparatively sluggish habits and a highly variable body temperature. This general description would doubtless fit many of the already known reptiles from the Carboniferous and Permian, but no one of these can yet be recognized as a direct ancestor to the later types.

In the harsh arid ages of the Permian and Trias were evolved hardier and more active carnivorous saurians, represented by the earliest dinosaurs, and especially by the "Pseudosuchians," such as *Ornithosuchus, Euparkeria.* Some of these small reptiles may have reared up on their hind legs in running, as certain lizards do; indeed the hind feet of *Euparkeria,* according to Broom, exhibit incipient adaptations to bipedal progression, while others were in all probability actively hopping types. But none of these animals show any very pronounced bird-like characters in the skeleton. Their structure, however, was, on the whole, of so generalized a type that the diverse peculiarities of the birds, pterosaurs and other groups could readily be derived from this source. In some of the Pseudosuchians the body is known to have been covered with horny plates, but others may have been clothed with the overlapping scales which must have preceded the evolution of feathers.

Thus the paleontological record as to the immediate ancestry of the birds is regrettably indecisive, but the principles of comparative anatomy appear to lead to some pretty safe inferences, as follows:

The transformation of long overlapping scales into feathers, whenever it did occur, was one of the critical steps in the evolution of birds. This transformation took place apparently over the whole surface of the body and along the legs and arms. No doubt it was correlated with the higher vitality and improved circulation of the pro-avis as compared with the ancestral reptile; no doubt also the air-retaining mesh of the feathery covering not only prevented undue radiation of heat from within during cold periods, but also screened off some of the burning heat of the sun. Possibly this feather-armor would also protect the ambitious aviator in his many falls from the branches. The pro-Aves were surely quick runners, both on the ground and in the trees, but it is not yet clear whether the upright position was first attained upon the ground or in the trees. They very early acquired the habit of perching upright on the branches, as shown by the consolidated instep bones, grasping first digit and strong claws of *Archæopteryx.* Their slender arms ended in three long fingers provided with large claws which were at first doubtless used in climbing.

These active pro-Aves contrasted widely in habits with their sluggish remote reptilian forebears. In the pursuit of their prey they jumped lightly from branch to branch and finally from tree to tree, partly sustained by the folds of skin on their arms and legs and later by the long scale-feathers of the pectoral and pelvic "wings" and tail. That they held the arms perfectly still throughout the gliding leap still appears doubtful, for all recent animals that do that have never attained true flight. I cannot avoid the impression that a vigorous downward flap of the arms, even before they became efficient wings, would assist in the "take off" for the leap, and that another flap just before landing would check the speed and assist in landing.

In correlation with this active arboreal life the brain became highly developed; the olfactory lobes grew smaller, the cerebra, optic lobes and cerebellum attained large size and high development. The brain-case was correspondingly expanded, while the skull as a whole acquired a very light construction. The earliest birds retained the sharp conical teeth implanted in distinct sockets which were characteristic of their "thecodont" ancestors (such as *Euparkeria*). The teeth and jaws were adapted for quickly snapping at living prey, perhaps insects. These entirely reptilian teeth, which in the case of Marsh's "toothed birds" bore an extraordinary resemblance to the teeth of mosasaurs, were retained long after the main adaptations for flight were established. But perhaps during the Cretaceous period the ancestors of modern birds lost their teeth as the horny beak at the front of the jaws grew backward.

The skull of birds is of a modified reptilian type and has no doubt been derived simply by the loss of the upper temporal bar, by the inturning of the pterygoid bones and by the enlargement of the internal nares. In short, the whole architecture of the bird skeleton, as indeed the whole internal anatomy, are unquestionably a modification of a primitive reptilian type. The consensus of opinion is that this ancestral type was nearly related to the primitive Archosauria (Diapsida), or two-arched reptiles, and was very widely removed from the mammals, mammal-reptiles, turtles, plesiosaurs and ichthyosaurs.

The hypothesis that the ratite birds have come off from some group of reptiles other than that which gave rise to the carinate birds is, in the writer's judgment, entirely untenable: first, because an examination of the skulls of various ratites and carinates shows agreement in fundamental plan, with minor, though well-marked, differences in details; secondly, because the entire organization of the ratites indicates merely a cursorial readaptation of carinate types; thirdly, because the tinamous are in many characters allied both to the ratites and to the carinates, and thus strengthen the conservative view that the class Aves is broadly monophyletic in origin.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXVII, pp. 39–191, pl. VI

Editor, Edmund Otis Hovey

A STUDY OF THE MORRISON FORMATION

BY

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NEW YORK
PUBLISHED BY THE ACADEMY
12 June, 1916

THE NEW YORK ACADEMY OF SCIENCES

(Lyceum of Natural History, 1817-1876)

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. XXVII, pp. 39-191, Pl. VI. 12 June, 1916]

STUDY OF THE MORRISON FORMATION[1]

BY CHARLES CRAIG MOOK

(Presented before the Academy, 3 May, 1915)

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[1] Manuscript received by the Editor 18 May, 1915.

INTRODUCTION

Preliminary Remarks

The present paper is the result of a study of the Morrison formation undertaken by the writer in connection with the monograph on the Sauropoda now in course of preparation for the United States Geological Survey by Professor Henry Fairfield Osborn. Library and laboratory work was done during the winters of 1912-1913, 1913-1914 and 1914-1915 at the American Museum of Natural History and at Columbia University. Field work was done in the summers of 1913 and 1914. The writer desires to express his thanks to Professor Osborn for the opportunity of studying the Morrison formation in the field, and for permission to use data gathered for use in the above-mentioned monograph. Conferences have been held with Professors A. W. Grabau, C. P. Berkey and D. W. Johnson, of Columbia University, who have made suggestions in regard to the work. Messrs. W. T. Lee, N. H. Darton, W. Cross and C. T. Lupton have added data regarding the distribution of the Morrison in the southern areas, and the director of the United States Geological Survey has given permission to use these unpublished data, and to use the map which was redrawn by Survey draughtsmen from an original by the writer. Valuable information has also been given by Mr. S. H. Knight, of Columbia University.

Definition of Formation

The name Morrison was first applied to the series of deposits under discussion, by Cross, in the Pike's Peak folio of the United States Geological Survey. It was proposed to include the series of clays, sandstones and shales which underlie the Lakota-Dakota series and overlie a white sandstone, which in turn rests on the Red Beds, at the village of Morrison, nearly west of Denver, Colorado. The names "Jurassic Beds," "Dakota Beds," "Variegated Beds," "Beulah Shales," "Atlantosaurus Beds," "Como Beds," "Gunnison Formation," "McElmo Formation" and "Flaming Gorge Formation" have all been applied to beds in various regions in a general way equivalent to the Morrison in eastern Colorado, though in some cases these terms have included more than the typical Morrison.

The name Morrison has been used extensively in the publications of the United States Geological Survey for this formation in other areas than the original area in eastern Colorado. As it was the first geographical name applied to the formation, it may be used as the valid formation name for the deposits concerned. In the present paper it will be used for the areas in western Colorado and Utah, where the beds have been known as Gunnison, McElmo, and in part Flaming Gorge, as well as for the more eastern representatives. The local names are often convenient, however, to designate the formation in particular localities.

The series is composed essentially of beds of variegated clays or marls, often described as "joint-clays," sandstones and shales, with minor elements of fresh-water limestones.

The formation has produced a small and not especially characteristic invertebrate fauna, a scant flora of cycads and fossil wood and a very characteristic and varied vertebrate fauna.

Physiographic Occurrence and Distribution of the Morrison Formation

The Morrison formation is generally exposed at the surface in two characteristic ways. The usual occurrences are in the steep faces of hog-backs and in the walls of river canyons. The hog-backs are long, even-topped ridges running practically parallel with the axes of mountain uplifts, with a comparatively steep slope on either side, but one side often

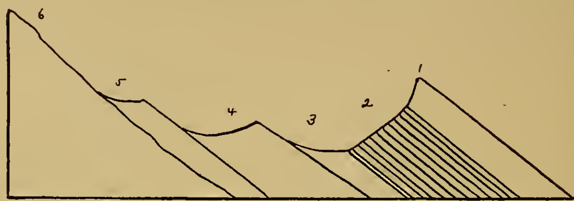

Fig. 1.—*Generalized section of Rocky Mountain hog-back, showing the usual physiographic position of Morrison outcrops.*

1.—Pre-Cambrian crystallines.
2.—Palæozoic.
3.—Red Beds.
4.—Sundance.
5.—Morrison.
6.—Capping sandstone (usually Cloverly or Lakota).

being steeper than the other. They are formed through uplift followed by erosion of the tilted and raised sedimentary beds which formerly covered or lapped against the mountains. The softer material is quickly eroded away, leaving ridges protected by cappings of harder strata. The Morrison formation is typically non-resistant, and so is usually found in

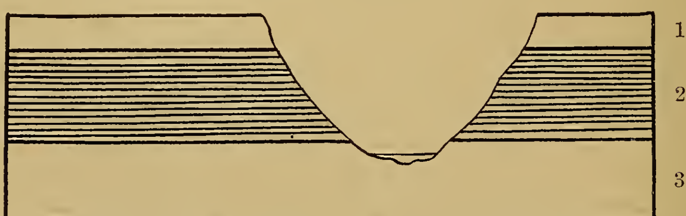

Fig. 2.—*Generalized section of a Rocky Mountain or Great Plains river canyon, showing a common position of Morrison outcrops.*

1.—Capping sandstone.
2.—Morrison.
3.—Red Beds.

the erosion cliffs on the inner sides of the hog-backs. Exposures of this kind occur in eastern Colorado, extending north into Wyoming and south into New Mexico, around the Black Hills, on both sides of the Laramie Mountains; around the Bighorn and Owl Creek Mountains; around the Wind River Mountains; south of the Uinta Mountains; and in the Grand

Hogback, which extends all along the western border of the Rocky Mountains in Colorado. The river canyon exposures of the Morrison are also widespread. They occur in the canyons of streams east of the Rocky Mountains, such as the Huerfano, Purgatoire, Cimarron and Apishapa; in the canyons of the McElmo, Dolores and other rivers in western and southwestern Colorado; and in central Montana.

Other outcrops occur as combinations of hog-back and canyon exposures, such as at Cañon City, Colorado; as local surface rock, such as in southeastern Colorado (see distribution map), and near Grand Junction, Colorado; and in the erosion of local anticlines, such as Como Bluff in south-central Wyoming, and in faulted masses, such as the Sioux Fault exposure in Wyoming.

Purpose and Scope of the Present Work

The purpose of the present paper is to interpret the Morrison formation, if possible, in regard to age, origin and paleophysiography. It is also desired to give a summary of the present knowledge, so far as it is available in the literature, together with some new field observations.

Among the problems which have been connected with the Morrison formation is that of its age. Some writers have held that it is Jurassic, and others that it is Comanchean. Still others have held that it is both Comanchean and Jurassic. It is desired to show that the Morrison is essentially Comanchean, but that some portions of it, especially in the western areas, may possibly be Jurassic.

Various opinions have been held regarding the origin of the Morrison. It has been considered marine, lacustrine, fluviatile and combinations of these. An attempt will be made in the present paper to show that the Morrison is essentially a broad alluvial plain, formed of coalescing alluvial fans, and possibly a true delta in the southeastern areas. It must have been deposited under conditions somewhat similar to those now existing in the great alluvial plains in eastern China.

The fauna and flora are listed for purposes of reference and summary.

STRATIGRAPHY

Morrison Formation in Eastern Colorado and New Mexico

General

The Morrison formation outcrops along the front of the Rocky Mountains in Colorado in a nearly straight line, from the Wyoming border to New Mexico, and south in New Mexico to a point a few miles south of

Las Vegas. The main line of outcrops then swings northeastward to a point 15 miles or so southwest of Clayton. The outcrops along the mountain front in Colorado and New Mexico occur in hog-backs. The northeast-southwest line of surface occurrence in New Mexico is an irregular cliff. The lines of outcrops are not completely continuous. At Golden the Morrison has been crowded out by igneous action, and at Manitou and other places it has disappeared through faulting. Outcrops also occur in the canyons of the Purgatory, Apishapa and other rivers in Colorado, and of the Cimarron in New Mexico and Oklahoma.

A. R. Marvine (1874, 3), in the seventh Annual Report of the U. S. Geological and Geographical Survey of the Territories, describes the "Jurassic" or the beds overlying the red series of supposed Triassic age as follows:

"*General characters.*—The series of strata lying next above the red beds form a group of rocks in which the thin-bedded and shaly element decidedly predominates. The outcropping edges of these beds have therefore generally been more eroded away than the harder beds above and below, so that they generally appear in valleys; and being soil covered, they are not usually well exposed.

"The arenaceous element still predominates, though argillaceous material is often present to a very large extent, while beds of impure limestone occur—one of which appears very persistent—and gypsum is frequent in thin layers, and sometimes occurs in workable quantities and of good quality. As before, red is the prevailing color, though a series of marked variegated shales occur, and weathering frequently produces an ashen-gray tint upon the surface. . . ."

Some of these beds are probably of lower horizon than the true Morrison.

The following description of the Morrison formation east of the Rocky Mountain front is given by Darton (1904, 8): "Its general character is nearly uniform throughout, a series of light-colored, massive clays, 'joint clays,' with thin beds of limestone and sandstone of fresh-water origin containing bones of saurians of the so-called 'Atlantosaurus' fauna. Its thickness averages less than 200 feet in most cases. It presents frequent and rapid variations in the local succession of beds, but the predominance of joint clays of chalky aspect and the occurrence of maroon and purplish layers among them are characteristic features." Lee speaks of the Morrison as "uniformly variable," a term especially applicable.

In the extreme northern part of Colorado the Morrison is said to rest upon the marine Sundance beds. Throughout most of the northern Colorado area it rests upon the red beds of the Chugwater formation. Further south in Colorado it rests upon the Fountain or Badito formations. South of Beulah, in southern Colorado, the Morrison rests directly upon the crystallines. In the canyon of Rio Cimarron, in New Mexico, it rests on the Exeter sandstone.

"The basal unconformity is one of widespread planation, with local shallow channeling, but no perceptible discordance of dips" (Darton, 1904, 8).

The Morrison is present at intervals from the Platte River to Colorado City. North of the gateway to the Garden of the Gods it is 130 feet thick and rests upon a bed of gypsum. It is partly exposed at Colorado City, where the beds are vertical. It is exposed again, after being cut off by faulting for a few miles south of Manitou, along the mountain front to the vicinity of Cañon City. It is also well exposed in this vicinity in a structural basin north of Cañon City. South of Cañon City the formation is not present for a considerable distance. It is present near Beulah, where it rests on the gneisses. North of Beulah the "Dakota" is said to rest directly upon the Fountain formation, showing the presence of an erosion interval between the Red Beds, or possibly the Morrison, and the "Dakota." The formation is exposed in the Greenhorn Mountains, where it rests partly upon the red beds and partly upon the gneisses. The more important areas of Morrison outcrops in the eastern region have been well described in various reports, and summaries of these descriptions are given below.

The Morrison formation is overlain by the Lakota-Dakota series, the lower beds of which are known in the southern Colorado area as the Purgatoire formation. The contact is essentially conformable, but it is sometimes extremely sharp, as north of Cañon City, and it is quite probable that in many areas at least there is a stratigraphic break of slight extent between the two formations.

NORTHERN COLORADO

The following sections are given by Darton of the Morrison formation in northern Colorado (1904, 8):

Section northwest of Laporte, Colorado

		Feet
"Dakota,"	Coarse sandstone, with conglomerate at base...............	..
	Gray massive shales, with thin limestone bed about 20 feet below top..	80
Morrison,	Limestone, gray, with algæ................................	6
	Sandy shale, reddish to buff, partly massive................	20
Pinkish and buff sandstone at top of Red Beds........................		60

Section east of Lyons, Colorado

		Feet
"Dakota,"	Sandstone, hard massive, buff..	..
	Olive green massive shale, with some sandstone layers.......	150
	Light grayish green massive shale......................	30
	Soft to hard gray sandstone, fine grained................	15
	Red, maroon, and green massive shale......................	150±
Morrison.	Massive buff sandstone, moderately fine..................	10
	Grayish green to maroon massive shale, with thin layers of fine grained sandstone.......	40
	Covered......................	25
Upper Wyoming.	Soft buff sandstone......	30

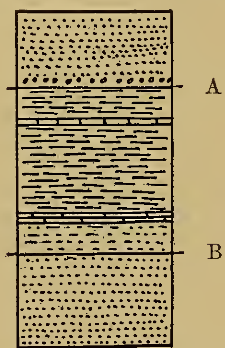

Fig. 3.—*Section of the Morrison and overlying and underlying beds at Laporte, Colorado.*

A-B = Morrison. Scale. 125 feet to 1 inch. (Darton.)

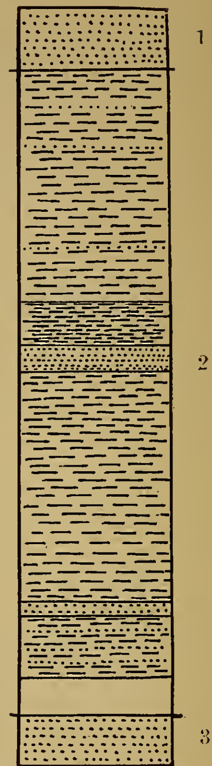

Fig. 4.—*Section of the Morrison and adjacent formations east of Lyons, Colorado.*

1.—Lakota; 2.—Morrison; 3.—Red Beds. Scale, 125 feet to 1 inch. (Darton.)

The Morrison formation in the vicinity of Boulder was described by Fenneman (1905, 9). The following remarks on the formation in this district are based on Fenneman's description. Sections of the Morrison at various places in this area differ greatly. In the main, however, the formation contains a large proportion of light-colored clays, some moderately indurated and others of flinty hardness, much gray sandstone, often calcareous, and at various horizons beds of highly compact limestone. A very much generalized section would present the beds in about the following order, beginning at the base: sandstone, clays, limestone, clays. The first and last members of the series are persistent, but the intervening clays and limestone may show two or three alternations and may inclose prominent sandstones. Fenneman estimates the maximum thickness to be a little less than 400 feet. The formation in this district overlies the Lykins division of the Red Bed series. The basal sandstone varies from 10 to 20 feet in thickness. It is persistent and massive and is used for building stone. It is somewhat calcareous. The lowest bed of limestone varies in level, but may be within 15 feet of the basal sandstone. The intervening levels are composed of clay which is covered by waste material. One bed of limestone 40 feet thick, according to Fenneman, occurs at South Boulder Canyon. At one locality there are three distinct limestones separated by sandstones, the uppermost of the three being about 30 feet thick. Next follows 75 to 100 feet of covered beds, probably soft clays. Limestones and clays interbedded follow this covered series, in turn followed by 15 feet or less of calcareous, iron-stained sandstone. Above this sandstone the formation is composed of dense, hard clays and argillaceous sandstones.

MORRISON

The deposits of the Morrison formation are not very well exposed at the village of Morrison, six or seven miles west of Denver, from which the formation takes its name. The beds outcrop on the western slope of the hog-back at this locality and are mostly covered by talus from the

FIG. 5.—*The Morrison formation at Morrison, Colorado, looking south*

heavy sandstones of the Lakota-Dakota series at the summit of the hog-back. The first discoveries of remains of the large dinosaurs of the so-called "Atlantosaurus fauna" were found about half way up the slope of the hog-back, on the northern side of the gap, through which Bear Creek crosses the hog-back.

The hog-back is capped by a ledge of heavy cross-bedded sandstone of the Dakota formation, underlain by white sands of the Lakota series.

Beneath these sands are the soft shales and clays of the Morrison for-

FIG. 6.—*The Morrison formation at Morrison, Colorado, looking east.*

mation. They are mostly pale green at this locality, with a few thin bands of sandstone and some variegated clays and red sandstones. The thickness here is evidently less than at Garden Park, near Cañon City, farther south, but more than in the exposures farther north in Wyoming. The upper and especially the lower contact could not be accurately determined. The formation appears to rest upon a coarse white sandstone, which in turn rests on deep red sandstones of the Red Bed series.

CAÑON CITY AREA

The Morrison formation is extremely well exposed in a number of localities north of Cañon City. A structural basin of Λ-shape, formed by down-faulting and down-folding, has protected the Paleozoic and Mesozoic sediments of the district so that they are bounded on the east, north and west by the crystallines.

A hog-back capped by the Lakota-Dakota sandstones extends northeast from Cañon City, and a similar hog-back extends northwest from a point a few miles east of Cañon City. The dips of these two hog-backs are steep at their southern ends, but as they converge the dips become less and change in direction. Instead of being toward the southeast and

FIG. 7.—*View northeast from Fremont Peak, near Cañon City, Colorado.* *A* indicates locality of the Marsh-Hatcher dinosaur quarry, *B* indicates the Morrison outcrops in the hog-back near Cañon City.

southwest respectively, the dip at the point where the Lakota-Dakota capping of the two hog-backs becomes continuous is towards the south. A short distance north of this point the dip lessens until the strata are nearly horizontal. Oil Creek, a tributary of the Arkansas River, cuts through this flat area, exposing the underlying rocks in a series of cliffs. North of this point a wider valley has been excavated, having the Triassic and lower beds as a floor. This valley is known as Garden Park.

The Morrison formation is exposed on the steeper eroded sides of the hog-backs, in the narrow gorge of Oil Creek and its tributaries, and in the

FIG. 8.—*Site of the Marsh-Hatcher dinosaur quarry near Cañon City, Colorado.*

FIG. 9.—*Near view of the central portion of fig. 8.*
An erosion channel in the lower clays, filled with a coarse sandstone, is shown.

steep cliff on the western border of Garden Park. At this latter point the beds are exposed from base to summit, affording a complete section. Several productive bone quarries have been operated at this point, and as these quarries exhibit the structure of the formation very well in some cases, they will be described in detail. The most important of these quarries is that which was operated by Professor O. C. Marsh, and later by J. B. Hatcher for the Carnegie Museum. This quarry is situated on the northeast bank of a dry brook-bed which joins Oil Creek just south

FIG. 10.—*Exposure of the lower beds of the Morrison formation about 100 yards northeast of the Marsh-Hatcher dinosaur quarry, near Cañon City, Colorado.*

of the entrance to Garden Park. The uppermost beds exposed at the quarry are red and brown joint-clays. Below these clays is a bed of rather coarse, heavy-bedded sandstone, about 5 feet thick. Below this is the bone-bearing sandstone, about 3 feet thick. It is a soft, coarse-grained sandstone, somewhat arkosic. In the exposures on the opposite side of the gulch the bone-bearing sandstone is distinctly cross-bedded. Below the bone-bearing sandstone is the sandstone of the quarry floor. This sandstone is heavy-bedded and is cross-bedded on a large scale. This cross-bedding makes the exact thickness difficult to determine. It is about 5 feet on the average, and the variation in thickness is not great. Two distinct types of cross-bedding are present in this sandstone. It is underlain by a bed of clay 1 or 2 feet thick. This clay is underlain by another sandstone with a lense-shaped cross-section. It is about 15 feet thick at its thickest portion and about 2 feet thick at a point 60 or 80 feet on either side of its center.[2] Below this sandstone is a bed of clay, 8 feet thick, bearing small obscure shells. Below this clay is a limestone 1 foot thick, which is underlain by 9 feet of clays. These clays are under-

FIG. 11.—*The Cope dinosaur quarry northwest of the Marsh-Hatcher quarry, near Cañon City, Colorado.*

lain by a bed of lime concretions, 1 foot thick, underlain by more clays. The beds below are not exposed in the gulch, but are exposed on the west bank of Oil Creek about a hundred yards northeast of the quarry. The section at this point is as follows: clays at the top, underlain by about 3 feet of sandstone, which are in turn underlain by about 5 feet of the bone-bearing sandstone. Below this are 3 feet of the quarry-floor sandstone. There is a sharp contact between this sandstone and the underlying clays. Below the quarry-floor sandstone there is a series of beds,

[2] See discussion of structures, p. 117.

36 feet in total thickness, which is mostly clay, but may contain thin beds of limestone or concretions where it is covered by a thin clay talus. Below this clay series is a heavy-bedded sandstone about 8 feet thick. This sandstone is underlain by a series of clays interbedded with thin layers of limestone and nodules. This series may be taken as the base of the Morrison formation in this region. It is underlain by the reddish arkosic sandstones of the underlying formation.

Another important quarry in this region is that operated for Professor E. D. Cope in 1877. This quarry is situated about 600 yards northwest

FIG. 12.—*The "Nipple," west of Garden Park, Colorado, looking east.*

of the Marsh-Hatcher quarry. It is situated at the top of the hill, and the beds exposed in it are the brown and white clays of the uppermost beds of the Morrison formation in this district. They are overlain by the coarse white sandstone of the Lakota or Purgatoire formation. The contact between the two formations is very sharp.

Another quarry operated for Professor Cope is situated about 500 yards east of the above-mentioned Cope quarry. It is situated at the base of a small conical hill, locally known as the "Nipple." It is at the top of the cliff which forms the western boundary of Garden Park. The productive bone level at this point is 20 feet or so below that of the other Cope quarry to the west. It is much higher than the bone level in the Marsh-Hatcher quarry. From the summit of the "Nipple" to the base of the cliff a complete section from the base of the Purgatoire to the upper members of the Red Bed series is exposed.

A section from the summit of the "Nipple" to the uppermost beds of the Red Bed series is as follows:

	Feet	Inches
1. At the summit of the "Nipple" and about 25 feet above the top of the cliff, white sandstone of the Purgatoire series	1	..
2. Brown joint-clay	4	..
3. Brown nodules	..	4
4. Brown clay	15	..
5. Gray clay (at the top of the cliff, contains dinosaur bones and is the productive bed of the above-mentioned Cope quarry).	5	2
6. Sandstone	1	..
7. Clay	1	..
8. (*a*, *b*, *c*) Clay, nodules and clay	3	..
9. Variegated clay	9	6
10. Sandstone	..	4
11. Clay	6	..
12. Sandstone	..	3
13. Variegated clay, gray, purple and green[3]	204	..
14. Cross-bedded sandstone	8	..
15. Clay	1	..
16. Sandstone	1 to 6	..
17. Clay	6	..
18. Sandstone	1	..
19. Clay	40	..
20. Sandstone	1	..
21. Clay	8	..
22. Sandstone	1	..
23. Clay	2	..
24. Sandstone	1	..
Total	319	1
		to
	319	7

25. Arkosic conglomerate. This conglomerate is here considered as belonging to the underlying Red Bed series, though it is possible that it may be the basal member of the Morrison formation. In the latter case the thickness of the formation would be increased by 40 or 50 feet.

The contact with the underlying beds is very indistinct, and the presence of an erosion interval between the Morrison and these underlying beds cannot be determined from the outcrops alone.

[3] The outcrop of this clay series is covered in many places with a thin clay talus, which may conceal some thin beds of limestone or nodules.

Marine fossils of Washita age have been found by Stanton (1905, 11) near Cañon City in beds immediately overlying the Morrison formation. This limits the age of the Morrison deposits near Cañon City to a certain extent. This question will be taken up again in the section on the age of the Morrison.

The general features in the Cañon City area which are especially worthy of notice are the prevalence of variegated joint-clays in the upper

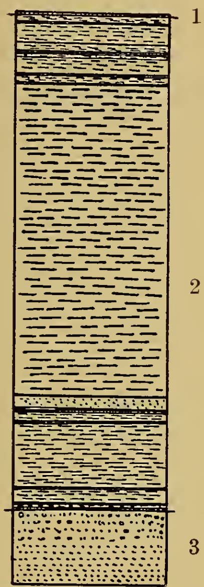

FIG. 13.—*Section of the Morrison and related formations at Garden Park, near Cañon City, Colorado.*

1.—Purgatoire; 2.—Morrison; 3.—Calcareous arkosic sandstone, probably the basal member of the Morrison, but may belong to the Red Bed series. Scale, 125 feet to 1 inch. (Section by the writer.)

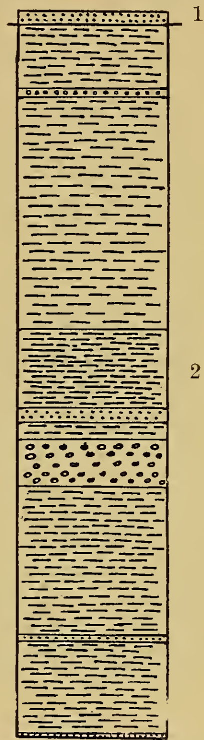

FIG. 14.—*Upper part of the Garden Park section.* (Fig. 11.)

1.—Purgatoire; 2.—Morrison. Scale, 12½ feet to 1 inch.

portion of the formation; the relatively larger amount of limestone, lime concretions and sandstone in the lower portion; the distribution of the dinosaur remains throughout nearly the whole thickness of the formation, though these remains appear to occur in definite levels; the sharp contacts of the sandstones and clays in the formation; the relatively small thickness of the individual sandstone members in most cases; and the lense-shaped cross-section of one of the principal sandstones.

The lense-shaped cross-section of one of the sandstone members indicates that it was deposited by a stream in a relatively narrow basin, which had been eroded in the underlying clays. The frequent occurrence of cross-bedding in connection with sandstones which have sharp contacts at the top and bottom appear to indicate deposition by streams or wind; the structure of the cross-bedding sometimes being that usually assigned to stream deposition, and in other cases being of the type usually assigned to deposition by wind. The frequent sharp contacts in the formation point to the period of deposition of the formation in this region as a period of alternating deposition and erosion, deposition being the dominant process in the long run.[4] The sharp contact at the top of the formation also indicates a period of erosion before the deposition of the basal sandstones of the overlying formation. This erosion interval may have been of long or short duration, so far as direct evidence from the contact is concerned.

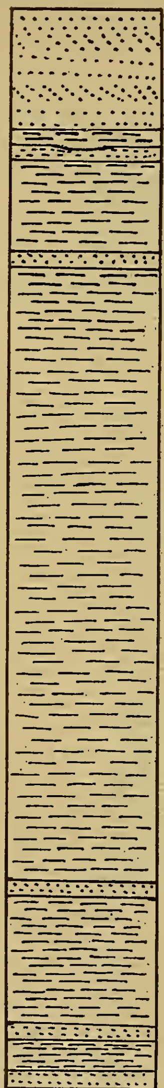

FIG. 15.—*Lower part of the Garden Park section.* (Fig. 11.)
Scale, 12½ feet to 1 inch.

CANYONS OF SOUTHEASTERN COLORADO

Lee (1901, 7) has described the Morrison formation in some of the river canyons in southeastern Colorado. He reports it to vary considerably in thickness from place to place, being 85 feet thick at the mouth of Plum Canyon, 132 feet in Red Rocks Canyon and 175 feet in Chaquaqua Canyon. The formation is made up largely of variegated clay-shales or joint-clays. Sandstone occurs in subordinate amounts, varying much in its position in the column, from one point to another. In Red Rocks Canyon there is a prominent sandstone at the base; there is none at all in Plum Canyon; in Chaquaqua Canyon, four miles from the mouth of Plum Creek, there is a coarse, cross-bedded sandstone 50 feet or so from the top of the formation. Across the canyon from this point, perhaps two miles away, 30 feet of limestone is found at the same horizon. Some of the sand is very pure and is used as a flux in assaying. The limestones also

[4] See discussion of structures, p. 118.

vary much in their occurrence. They are usually more or less argillaceous. "The relative amount and position of sandstones, shale and limestones at any one point is no indication that a similar relation will be found at any other point. There is no abrupt lateral change, but the various beds blend into each other or pinch out laterally in a gradual though somewhat rapid manner, so that, while no sudden change is seen, a comparison of sections a few miles apart may show a total change in kind and relation of materials" (Lee, 1901. 7; 1902. 5). Dinosaur bones

FIG. 16.—*The "Nipple," looking west from Garden Park, Colorado.*
This view is in the opposite direction from that in fig. 12. The section shown in fig. 13 was taken in this cliff.

were found at many horizons. Some of these have been identified by Barnum Brown as *Morosaurus* and *Diplodocus.*

The Red Beds, Morrison and "Dakota" all have the appearance of being conformable, though critical examination has shown that there is evidence in favor of concluding that there is a stratigraphical break both above and below the formation. There is distinct evidence of erosion at the surface of the Morrison, below the "Dakota (Purgatoire), in the presence of undulations in the line of contact with the "Dakota" (Purgatoire).

The Morrison lies on beds of gypsum in these localities. This gypsum is not differentiated sharply from the underlying Red Beds. There is often a transition from Red Beds into gypsum. The change from the gypsum to the lower members of the Morrison is abrupt, and the gypsum often decreases in thickness where the Morrison is thick, and the reverse. "It is possible, therefore, that the gypsum beds were exposed and slightly eroded previous to the deposition of the shales" (Lee, 1901, 7).

The following sections of the Morrison in this area are given by Lee (1901, 7):

Section near Mouth of Plum Canyon

		Feet	Inches
Dakota (Purgatoire).	Two massive sandstone layers separated by a soft shale of varying thickness; leaf impressions near the top of the upper division	140	..
Morrison,	Greenwich clay shale, soft and fine grained	11	..
	Dull red clay shale, soft and fine grained	12	..
	Brown to yellow shale	10	..
	Argillaceous limestone; numerous fine dark laminæ	..	6
	Buff-colored shale	..	18
	Argillaceous limestone; numerous fine dark laminæ	..	6
	Variegated joint clay	18	..
	Argillaceous limestone, fine grained and hard, with contorted laminæ	2	..
	Variegated shales; very soft and easily eroded	30	..
Red Beds,	Dark shales containing irregular masses of gypsum	15	..
	Gypsum containing streaks of clay	..	18
	Variegated shale containing nodular-like masses of gypsum which vary in size from grains to masses a foot or more in diameter. About one third of the mass is gypsum	8	..
	Gypsum in well-defined layers. Often separated by layers of clay	25	..
	Massive gypsum	5	..
	Red gypsiferous shales, soft and regularly bedded	30 to 40	..
	Red calcareous sandstone, oölitic, cross-bedded. Individual layers variable in thickness and character. Near the top it becomes shaly and passes gradually into the gypsiferous shales above	60	..
	Red sandstone, massive, cross-bedded	175 to 200	..
	Red arenaceous shale	6	..
	Red sandstone	1	..
	Fine red shale	4	..
	Even-bedded red sandstone	9	..
	Red arenaceous shale	2	..
	Red sandstone, cross-bedded; the individual layers thin out laterally	40	..
	Poorly cemented red sandstone alternating with layers of shale	15	..

	Feet	Inches
Massive red sandstone	5	..
Soft red sandstone containing hard layers which are ripple-marked	30	..
Hard, white, argillaceous limestone composed of numerous thin layers; greatly contorted	4	..
Red sandstone in thin flaky layers	15	..
(River bottom.)		

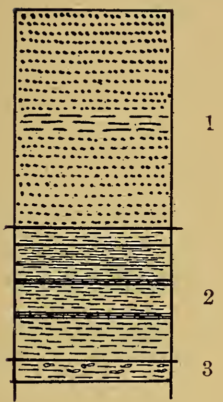

FIG. 17.—*Section of the Morrison and related formations in Plum Canyon, Colorado.*

1. — Purgatoire-Dakota ; 2. — Morrison ; 3.—Gypsum at the top of the Red Beds. Scale, 125 feet to 1 inch. (Lee.)

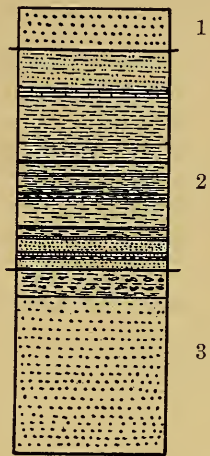

FIG. 18.—*Section of the Morrison and related formations in Red Rocks Canyon, Colorado.*

1.—Purgatoire ; 2.—Morrison ; 3.—Gypsum and Red Beds. Scale, 125 feet to 1 inch. (Lee.)

Section in Red Rocks Canyon

	Feet	Inches
Dakota (Purgatoire) sandstone.		
Brick red arenaceous shale, containing bands of hard, fine-grained sandstone	25	..
Reddish limestone having a conchoidal fracture and very brittle	3 to 5	..
Soft dark clay shale	30	..
Light brown clay shale	11	..
Argillaceous limestone	..	6
Brown shale	7	..
Concretionary limestone	1	..
Variegated clay shale; joint structure	7	..
Fine yellow paper shale	3	..
Argillaceous limestone, finely laminated	..	6
Fine shale	..	18
White limestone	1	..
Variegated clay shale	15	..

	Feet	Inches
Argillaceous limestone, finely laminated	..	8
Yellow shale	4	..
Sandstone containing agate either in concretionary masses half an inch or more in diameter or disseminated generally throughout the mass	1	..
Sandstone, easily crumbling; made up of thin layers	8	..
Massive sandstone, poorly indurated	2	..
Fine paper-shale	2	..
Massive sandstone, poorly indurated	7	..
Gypsum interstratified with layers of clay	12 to 20	..
Red sandstone (Red Beds)	..	..

R. C. Hills (1900, 7) describes the Morrison of the Walsenberg quadrangle as follows:

"*Morrison formation.*—This formation aggregates about 270 feet in thickness at the southern extremity of the Greenhorn Mountains, where there is a narrow outcrop extending along the foothills a distance of about 5 miles and passing on beyond the west boundary of the quadrangle. It is also exposed along the canyons of the Cuchara and Huerfano for a distance of over 20 miles. About midway between the extremities of the Greenhorn Mountains outcrop the inclination varies from 45° to nearly vertical. The lower portion consists of about 60 feet of soft, white sandstone having a conglomerate layer at the base. This is followed by hard, shaly beds of pinkish and greenish tints, breaking into fragments with conchoidal fracture. The upper portion consists of variegated shales and clays alternating with bands of hard, fine-grained limestone, often containing vermilion-colored cherts. One band of conglomerates a few feet thick contains green pebbles. At one point the basal sandstone overlaps the Badito formation, and rests on the Archean at an angle of 15°. In the canyons of the Huerfano and Cuchara the strata have but slight inclination except where an upward bulge brings an area of the Fountain to the surface. Here the thickness of the Morrison is less than 100 feet, and corresponds to the upper, variegated part of the Greenhorn outcrop, the lower part being entirely wanting. There is still considerable doubt as to the true position of this formation in the time scale, and the assignment to the Jura-trias is therefore provisional."

In the Apishapa quadrangle the Morrison consists of blocky clay or argillite, according to Stose (1912, 7), with thin beds of limestone and some soft sandstone. The argillites are of brilliant colors, ranging from white to dark brown or red, and to green and drab. Only 120 feet of the formation is exposed in the quadrangle. Stose gives the following composite section of the upper part of the Morrison in Huerfano Canyon:

	Feet
Sandstones of the Purgatoire formation.	
Variegated shale and compact argillite, green drab, and dull maroon in color, largely covered	37
Massive gray sandstone having ocher colored spots, with soft fine-grained chocolate colored sandstone above and red layers toward the top. Largely covered. Exact relation not known	58±
Greenish-gray shale and compact argillite with 6-inch beds of impure limestone and short lenses of sandstone. The limestones contain small fresh-water gastropods and lamellibranchs	25±
	120±

Two miles above the mouth of Jones Lake Fork there is an exposure of 100 feet of the formation. The uppermost beds at this point are covered, but there is about 30 feet of reddish shale with calcareous concretions, underlain by 8-10 feet of limestone. At the base is green argillite.

Gilbert gives the following partial section at the mouth of Jones Lake Fork (Stose, 1912, 7):

	Feet
Thin sandstone and gray shale (Purgatoire formation).	
Chocolate colored shale	16
Soft pale gray sandstone freckled with brown, weathering pale brown	10
Variegated compact blocky shale, red, chocolate, green and white, with bands of fine sandstone, some tough and brown. The lowest sandstone is a fine-grained rock freckled with pale yellow.	51
	77

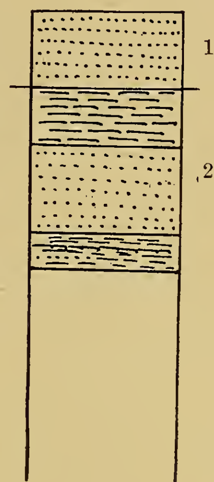

FIG. 19.—*Composite section of the upper part of the Morrison formation in the Huerfano quadrangle, Colorado.* 1.—Purgatoire; 2.—Morrison. Scale, 125 feet to 1 inch. (Stose.)

EASTERN NEW MEXICO AND OKLAHOMA

The Morrison occurs a few miles east of Folsom, New Mexico, in the canyon of the Rio Cimarron (Lee, 1902, 5). It consists, at this point, of 25 to 50 feet of variegated clay-shales overlying the upper gypsum member of the Red Bed series. These clays thicken farther east, and 14 miles east of Folsom they are about 200 feet thick. The following section by Lee was measured at this point:

Dakota (Purgatoire). Sandstone, massive and quartzitic, somewhat conglomeratic in places.

Shales (Morrison). 200 feet of varicolored shales with local beds of brittle limestone and lime concretions. A coarse, loose-textured, cross-bedded sandstone occurs near the top.

Red Beds. Deep red sandstone.

Still farther east, below the junction of Long Canyon and Rio Cimarron, the Morrison formation is exposed in an isolated mesa which stands in the midst of the canyon. A section at this point, measured by Lee, is as follows:

Section in Canyon of Rio Cimarron east of Long Canyon

		Feet
Dakota (Purgatoire).	Sandstone, massive, quartzitic, cross-bedded, slightly conglomeratic in places. A thin seam of blue clay 100 feet from the base	250
Shales (Morrison).	Colored shale containing layers of argillaceous sandstone and limestone	40
	Coarse grained loose textured sandstone	50
	Conchoidal limestone with clay and coarse sand at the base	10
	Arenaceous shale	10
	Conchoidal limestone	1 to 3
	Variegated shale	40
	Argillaceous limestone	3
	Shale containing irregular seams and masses of agate - like concretions, colored in varying shades of blue and pink	40
	Sandstone	5
Red Beds.	Gypsum interbedded with clay	20
	Red to purple sandstones and shales	..

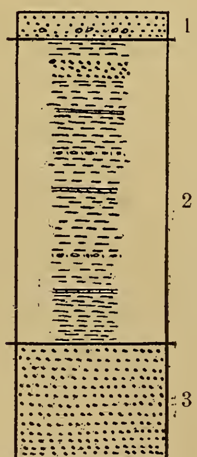

FIG. 20.—*Section of the Morrison and related formations in Rio Cimarron Canyon, 14 miles east of Folsom, New Mexico.*

1.—Purgatoire; 2.—Morrison; 3.—Exeter. Scale, 125 feet to 1 inch. (Lee.)

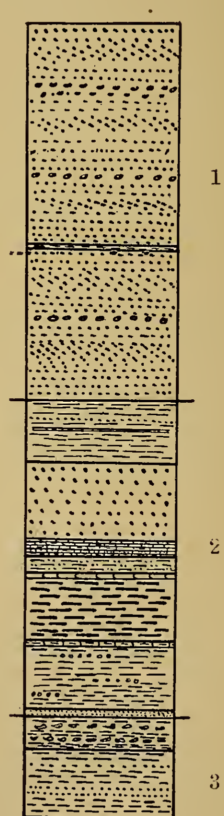

FIG. 21.—*Section of the Morrison and related formations in the canyon of Rio Cimarron east of Long Canyon, New Mexico.*

1. — Purgatoire-Dakota; 2. — Morrison; 3.—Red Beds and gypsum. Scale, 125 feet to 1 inch. (Lee.)

The formation was traced by Lee eastward from Folsom to a point seven miles east of the boundary between New Mexico and Oklahoma. The formation is made up, as usual, of variegated clays with minor amounts of sandstone and limestone. "All the members of this formation vary laterally in character and thickness. No two sections exhibit the same order of succession nor the same relative proportion of materials" (Lee, 1902, 5). One member which is persistent in this area is a thin bed of agate-like concretions near the base of the formation.

"In the vicinity of Exeter post-office the shales are separated from the underlying Red Beds by a well-marked unconformity. The Red Beds were thrown into gentle undulations and these undulations eroded previous to the deposition of the younger sediments upon them. Several miles west of Exeter post-office the shales rest upon the eroded edges of a local arch, from the top of which about sixty feet of the Red Beds had been removed previous to the deposition of the shales. The gypsum, which is here considered as the top of the Red Beds, appears in the flanks of the truncated arch. From this point eastward for several miles angular unconformities were noted at the top of the Red Beds" (Lee, 1902, 5).

Another section was measured by Lee a few miles east of Exeter post office. The formation is exposed on buttes and mesas in the midst of the canyon. Limestone is an important constituent of the formation at this point. The section is as follows:

Section near Exeter Post Office, in the Canyon of the Rio Cimarron

		Feet	Inches
Dakota (Purgatoire).	Hard quartzitic sandstone	78	..
Shales (Morrison).	Shale, arenaceous in places	10 to 15	..
	Lime concretions	..	6
	Red shale	8	..
	Sandstone	4	..
	Sandstone and shale (debris covered in places)	50	..
	Dark red shale	30	..
	Coarse sandstone	4	..
	Blue clay	2	..
	Calcareous clay	2	..
	Blue clay shale with seams of limestone	30	..
	Hard brittle limestone	1	..
	Shale with thin seams of limestone	20	..
	Shale with impure limestone and sandstone bands and irregular masses of agate	10 to 15	..
	Hard brown, nearly pure limestone	5	..
	Unexposed	20	..
Exeter.	White sandstone, massive below but passing to well define layers above	35	..
	Loose textured and readily weathering sandstone	8	..

		Feet	Inches
	Massive chalky white sandstone, cross-bedded and cavernous weathering	15	..
	Soft shaly sandstone	2	..
	Massive evenly laminated sandstone, ranging in color from red at the base to white at the top	15	..
Red Beds.	Red sandstone layers interstratified with red and purple shales	..	..

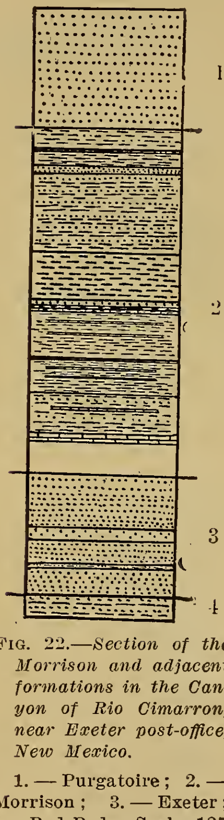

FIG. 22.—*Section of the Morrison and adjacent formations in the Canyon of Rio Cimarron, near Exeter post-office, New Mexico.*

1. — Purgatoire ; 2. — Morrison ; 3. — Exeter ; 4.—Red Beds. Scale, 125 feet to 1 inch. (Lee.)

Near Exeter post office a sandstone formation appears between the Morrison and the Red Beds. It lies unconformably upon the Red Beds. It apparently underlies the Morrison conformably . It is a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color. The lower members are pink, while those above are lighter colored. It has the appearance of being composed of the coarse material eroded from the Red Beds. The sandstone has a maximum thickness of 75 feet, and extends from a point several miles west of Exeter, where it thins out, eastward to the Oklahoma-New Mexico line, where it drops beneath the canyon bottom. No fossils of any kind have been found in this sandstone. It occurs in a series of nearly perpendicular cliffs, making a broad continuous band along the canyon sides (Lee, 1902, 5).

The Morrison in this locality, according to Lee (1902, 5), "rests in turn (1) upon the gypsum conformably; (2) upon the gypsum and underlying Red Beds unconformably; (3) upon the Exeter sandstone conformably." Lee also notes that the Morrison shales, as a formation, do not vary to any considerable extent in character or thickness at this locality. "Whatever may have been the physical conditions prior to the deposition of the shales [Morrison], it is evident that the shales were deposited over a well-graded surface. It follows also that there was a somewhat notable time-interval between the Red Beds and the shales. A part at least of this time-interval is represented by the unconformity between the Red Beds and the Exeter sandstone. It is uncertain whether there is a time break between the Exeter sandstone and the overlying shales. However this may be, the seeming conformity which exists in many places between the Red Beds and the shales is deceptive. The contact really represents the whole time indicated by the unconformity between the Red Beds and the Exeter sandstone and the time required to form the Exeter sandstone, besides the possible period between the deposition of the Exeter and that of the shales" (1902, 5).

The Morrison formation is exposed in the canyon of the Canadian River. This river flows in a narrow gorge for fifty miles or so, then in a broad valley bordered by high escarpments. The thickness of the formation is approximately 300 feet. The beds are composed mainly of variegated clay-shales and friable sandstones. Limestones also occur in limited extent. In some localities the limestone layers are all near the top, and at others they are differently distributed. In no two sections do the limestones occur at the same horizon. The sandstones comprise a considerable part of the formation, perhaps one-third. The separate beds are in some cases firm and in others very friable. They grade from sands of pure silica to nearly pure clay. A slightly cross-bedded sandstone of considerable persistence may be seen in places near the middle of the formation. The shales contain red, brown and green members.

The contact with the overlying Purgatoire is abrupt, but without definite evidence of disconformity. A coarse, massive, pink sandstone occurs at the base. The contact with the underlying beds is sharp, but without distinct disconformity (Lee, 1902, 5).

The following section was measured by Lee, north of Bell Ranch:

Section at the Escarpment north of Bell Ranch

		Feet
Dakota (Purgatoire).	Sandstone, coarse, massive and quartzitic	250
Shales (Morrison).	Variegated shale containing numerous thin bands of limestone and sandstone	50
	Argillaceous fissile sandstone	10
	Coarse sandstone	13
	Bluish-green shale with a few bands of sandstone and impure limestone	45
	Coarse massive sandstone	15
	Variegated clay shale	12
	White sandy shale	5
	Coarse white sandstone, cross-bedded in places	13
	Colored sandy shale	15
	Argillaceous sandstone	6
	Coarse sandstone containing lime concretions in places	15
	Variegated shale containing thin layers of sandstone	36
	Red and green shales	12
	Poorly exposed. Shale seen at intervals	65
	Rusty brown to red sandstone with bands of red clay	10 to 50
?Sandstone.	Massive pink to white sandstone. Forms a persistent cliff.	50 to 100
Red Beds.	Friable sandstones and shales in thin layers, red to deep purple in color	..

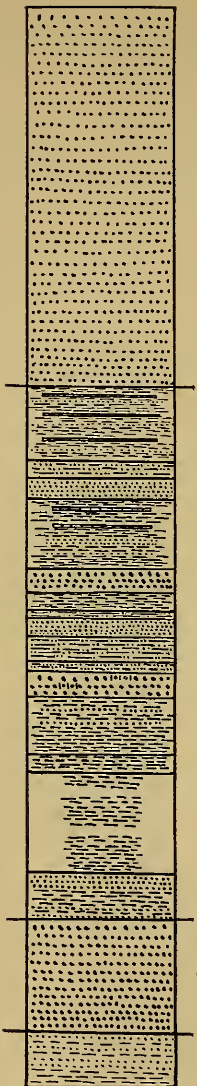

Fig. 23.—*Section of the Morrison and adjacent formations in the escarpment north of Bell Ranch, New Mexico.*

1.—Purgatoire - Dakota; 2.—Morrison; 3.—Exeter; 4.—Red Beds. Scale, 125 feet to 1 inch. (Lee.)

Morrison Formation in Western Colorado and Eastern Utah

A series of variegated clays and shales occur in many localities in western Colorado and eastern Utah, which correspond lithologically and stratigraphically with the Morrison formations east of the Rocky Mountains. The meager invertebrate fauna of these clays and sands agrees with that of the eastern Morrison, and the discovery by Riggs in 1900 of a vertebrate fauna in these beds, consisting of practically the same forms as the fauna of the eastern Morrison, proves that some part, at least, of these western clays corresponds to all or certain parts of the Morrison formation east of the Rocky Mountains.

The clays under discussion have been referred to in different localities as the Gunnison formation, McElmo formation, Flaming Gorge formation, "Lower Dakota" and "Jurassic beds." The strata included under some of these terms undoubtedly contain beds that do not correspond with any part of the eastern Morrison formation. This fact does not preclude the probability that in general these beds correspond with the eastern Morrison.

The western representatives of the Morrison formation occur in isolated areas preserved by faulting, as at Crested Butte; in hog-backs, as in the exposures east of Vernal; and in the walls of river canyons as at Grand Junction. Detailed descriptions of the formation at some of the better known localities are given below.

The following description of the Gunnison formation in the Crested Butte quadrangle is given by Eldridge (1894, 3):

In the Anthracite-Crested Butte quadrangles the Gunnison formation rests unconformably on the maroon and older formations. It consists of quartzites and shales, with a minor amount of limestone. Its thickness is from 300 to 450 feet. At the base of the formation is a heavy white quartzite, 50 to 100 feet thick, usually in a single bed. Above this is a blue limestone, which contains shells of *Limnea, Valvata* and *Cypris.* In some cases this limestone is succeeded by more sandstones, and in other cases these sandstones are absent. The upper part of the formation consists of gray, drab, pink and purple clays and marls, through which run thin intermittent beds of drab limestone.

The lower part of this formation may correspond to the La Plata sandstone rather than to the McElmo or Morrison. It is quite probable, however, that most of the formation is equivalent to the latter.

This locality is about midway between the eastern front of the Rocky Mountains and the areas west of the mountains, where the Morrison has a great thickness. The presence at this point of Morrison beds of medium thickness indicates the probable former extension of the deposits across the country now occupied principally by the crystallines of the Rocky Mountains.

Peale (1877, 2) describes "Jurassic shales" in San Miguel and Dolores canyons and in the Uncompahgre Valley. The creeks tributary to the Gunnison cut through Dakota and soft "Jurassic" shales into the underlying red sandstones. The San Miguel cuts through "Jurassic shales." The following section on a creek tributary to it is given by Peale:

1). Upper Dakota sandstone.
2). Lower Jurassic shales.
3). Jurassic variegated beds.
4). Massive red sandstone, light colored.

At one point the "Jurassic shales" rest on the gneiss, according to Peale. He discusses the "Jurassic shales" as follows: "Immediately above the red beds is a group of shales and marls, with thin bands of limestone near the base. These beds are variegated in color, and correspond, lithologically and stratigraphically with the beds that, in eastern and central Colorado, I referred to the Jura. . . . They appear to correspond closely with the beds measured in the section on the Gunnison in 1874."

The Gunnison formation of Eldridge was divided by Cross in the Telluride folio into two formations, the La Plata formation corresponding to the lower part of the Gunnison formation of the Crested Butte section, and the McElmo formation corresponding to the upper part of the original Gunnison. The McElmo corresponds much more closely with the eastern Morrison than the La Plata, but in some localities it is difficult to separate the La Plata from the McElmo, and it is possible that some portions of the La Plata are represented in the eastern Morrison.

In the present discussion the McElmo will be considered as related to the eastern Morrison formation. The following descriptions are from Cross (1899, 3) in the Telluride folio of the United States Geological Survey:

The McElmo or Morrison formation in the Telluride quadrangle is a variable series of shales and sandstones, with the latter more prominent than is usual in this formation. The thickness varies from 650 to 900 feet. The sandstones are generally fine-grained, quartzose, yellow or gray, and usually friable. Some of the sandstone beds are massive and reach a thickness of 50 feet. More often they are separated by shale layers. Cross-bedding occurs in some of the sandstones. Many of the sandstones contain small flat flakes of green shale.

The shales or clays are reddish or greenish, or a mixture of both colors. They are generally calcareous and sandy. Sandstone layers occur in the shale. In following the formation along the walls of the San Miguel Canyon a shale stratum may be found to change, within a short distance, to an alternation of sandstone and shale. The reverse change often occurs in the case of sandstone beds.

At the base of the McElmo in this area is a highly colored shale resting on the La Plata sandstone.

The following is a typical section of the McElmo formation in the Telluride area:

	Feet
Shale	11
Sandstone, rather fine grained	22
Shale, sandy, with many thin layers of fine-grained sandstone	53
Sandstone, coarse, grading into conglomerate of quartz and chert pebbles at base	24
Shale, dull red or green, with subordinate thin bands of very fine-grained calcareous sandstone	155
Sandstone, coarse grained, cross-bedded	48
Shale	11
Sandstone, massive	16
Shale, red, with thin sandstone layers	53
Sandstone, white	11
Shale, red, with thin sandstone layers	29
Sandstone, white, cross-bedded	22
Alternating red shale and gray sandstone	85
Sandstone, massive in lower part, but with thin red shale partings above	80
Shale, sandy	32
Sandstone	8
Shale, sandy, chocolate colored in upper part, thin layers of sandstone in upper part	64
Total	724

"Other sections show many changes in the relative development of sandstone and shale at any given horizon. The conglomerate, number 14 of section, is similar to the Dakota in character, but is very variable in development. Holmes noted the presence of a conglomerate near the top of his 'Lower' Dakota in the plateau country westward, and sporadic developments of the same in the Morrison beds may be seen in various places at the base of the Front Range." Owing to the similarity of the McElmo beds with the Dakota on the one hand and the La Plata on the other, it is difficult to determine the exact upper and lower boundaries of the formation.

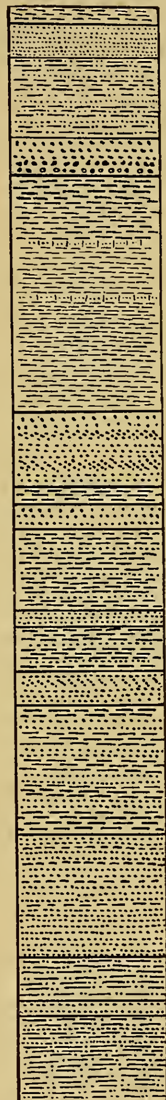

FIG. 24.—*Section of the Morrison formation in the Telluride quadrangle, Colorado.*

Scale, 125 feet to 1 inch. (Cross.)

The Morrison (McElmo) in the Rico quadrangle, according to Cross (1905, 10), is 500 feet or less in thickness. It is composed largely of shales at this point, usually of apple green or dark red color, occasionally variegated red or green. The shales alternate with sandstones in varying proportions. The sandstones are white, even grained, and friable; they often grade laterally into sandy shale and finally into clay shale.

In the Ouray quadrangle, the Morrison (McElmo) beds are described by Cross and Howe (1907, 6) as a series of alternating shales and sandstones, which vary in thickness and character. The average thickness in this district is from 500 to 700 feet, the maximum being about 800 feet. The shales are varied in color. Green predominates, but in the lower beds reds and browns are conspicuous. Many of the shale beds are fine-grained and porcelain-like, but usually they contain sand. Sandstones are numerous, and are usually quartzose, fine-grained, gray and friable. They vary considerably in thickness in short distances, and often show transition to shale or clay beds. The separate sandstone layers seldom exceed 20 feet in thickness.

The following section of the Morrison (McElmo) formation is given by Cross and Howe for a locality south of Dexter Creek in the Ouray quadrangle:

	Feet
Shales, slaty, black, alternating with shaly bituminous sandstone; individual layers less than 2 feet thick	16
Sandstones, yellowish or greenish, with shaly layers	14
Quartzite, dense, gray	6
Shales, sandy, black; and fine-grained sandstones, largely quartzitic, thin bedded	23
Quartzite, hard, white	20
Sandstone, friable, white, containing clay	10
Porcelain shales and thin argillaceous sandstones	21
Shales, fine-grained near top, dense, porcelain-like below, with sandy layers	42
Quartzite, massive, white, more friable below, with thin clay layers near base	5
Sandstone, coarse, white, lower portion indurated and containing a 2-foot shale layer	13
Shale, green, with some purple and gray layers, very fine grained, much of it hard like porcelain; some sandy layers, more numerous near base; dark red; rests upon 5 feet of very white and massive porcelain shales.	50
Shale, red, sandy and containing shaly sandstone	16
Green and red porcelain shales and sandstones with a 2-foot pink, fine-grained limestone at the top	78
Sandstone, massive, green above, white below	9
Sandy shales and shaly sandstones, green, white and red	69
Sandstone, white, saccharoidal	20
Sandstones and sandy shales, with some porcelain layers, red and green	26
Sandstone, massive, fine-grained, gray, white	10
Sandy shale and sandstone, alternating green and red	20
Sandstone, fine, greenish white, becoming red and shaly below	17
Sandstone, extremely massive, white; red stains from shales above; quartzite in lower part and a thin green shaly layer near base	70
Sandstones, with thin limestones and calcareous shaly layers; some reds and pinks, prevailing colors buffs and yellows	120
Sandstones, heavy bedded, saccharoidal	11
Shale and thinly bedded buff sandstone	10
Quartzite, light colored, with bluish stains	18
Sandstones and shales, red	65
	779

La Plata sandstone.

In the La Plata quadrangle the Morrison (McElmo) is described by Cross, Spencer and Purington (1899, 4) as a series of alternating shales and sandstones, from 400 to 500 feet thick. The sandstones are usually characterized by the presence of green shale flakes; 50 or 60 feet below the top of the formation, there is a bed of coarse white conglomerate separated from the "Dakota" by a series of red and green shaly beds. The conglomerate contains white and dark quartz pebbles, and is 10 to 15 feet thick.

The Morrison (McElmo) formation is described by Cross (1910, 4) in the Engineer Mountain quadrangle, as follows:

"In the Engineer Mountain quadrangle the McElmo has a thickness of 400 to 500 feet. It is here composed more largely of shale than in the Telluride quadrangle, where its thickness on the San Miguel River is nearly 1000 feet and where sandstone forms its most important element. Shale and sandstone alternate in the formation in variable proportions. The beds of shale as a rule are colored some shade of green, but are locally pink or deep Indian red, and they include some variegated red and green bands. The shales are fine grained and sandy and occur in homogeneous bands, in places several feet thick, with little or no distinct lamination. The sandstones are fine and even grained and friable in texture; those of the lower portion resemble the La Plata sandstone, and at least one of the upper beds is very similar to the Dakota sandstone. The arenaceous layers are white or yellowish and locally grade horizontally and vertically into sandy shale and thence into clay shale. In the upper part of section there is a fine-grained conglomerate which is practically identical with the lowest conglomerate of the Dakota. The large number of crumbling beds in the formation cause numerous gaps in all discovered exposures, and no detailed section can be given."

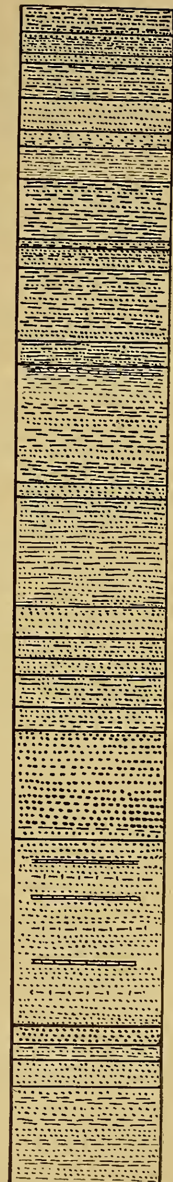

FIG. 25.—*Section of the Morrison formation on Dexter Creek, Rico quadrangle, Colorado.* Scale, 125 feet to 1 inch. (Cross.)

GRAND RIVER AREA

The Morrison (McElmo) formation is well exposed along the Grand River, from its junction with the Gunnison River westward into eastern Utah. For some distance east of the junction with the Gunnison River it is also exposed in the walls of the canyon of the Grand River. West of Grand Junction, the beds are exposed on the south side of the river only. The exposures are usually several miles south of the river, and occur partly in the high cliff which forms the northern boundary of the Uncompahgre Plateau, and partly in a lower southward facing cliff a short distance farther north.

A short distance west of Mack the river turns sharply to the south, and cuts across the formations, giving complete sections of several of the formations.

Riggs (1901, 4) describes the Morrison (McElmo) beds near Fruita as a series of four principal members, aggregating 600 to 700 feet in thickness. The lowest of the four he assigns to a marine origin. It is 100 to 120 feet in thickness, consisting of bluish-gray, gypsum-bearing clays, with thin layers of fine-grained sandstone, and very thin layers of nodular limestone. This division grades into the second, which he assigns to a fresh-water origin. The second division contains no limestone, and consists largely of homogeneous and massive clays. A ledge of fine-grained sandstone occurs near the base. The second division is about 100 feet thick, and consists of greenish clay shale, containing occasional ledges of green sandstone and a few layers of clay nodules. Conspicuous banding is not present. The third division consists of a darker zone containing frequent ledges of cross-bedded sandstone. This series is 40 to 50 feet thick. The sandstones vary from fine-grained to coarse-grained, and from thin layers to massive layers. They are often rich in iron and brown in color. In places this division is entirely absent. The fourth division consists of variegated clays 300 feet or more in thickness, characterized by brilliant coloring and conspicuous banding. "The alternation between green and purplish bands does not mark any variation in the nature of hardness of these massive joint clays." Thin layers of calcareous nodules and sandstones occur. Nodular gray sandstone and thick ledges of cross-bedded sandstone, and lenticular masses of sandstone occur locally.

Lee (1912, 6) has described the Morrison (McElmo) beds in the Grand River region as a variegated sandstone and shale formation lying between the red beds and the Cretaceous beds. The formation here has a thickness of 682 feet. The upper limit is marked by an erosional unconformity. The formation is divisible into two general divisions which are distinct lithologically, but still represent continuous deposition. The lower member [Nos. 9-17 in section] consists principally of even-bedded flaggy sandstone. This is the series Riggs referred to as the marine Jurassic. It contains some limestone. The upper member [Nos. 5-8 in section] consists principally of variegated shale with a coarse conglomerate near the top.

The following section of the Morrison (McElmo or Gunnison) formation is given by Lee:

Section of Rocks exposed in Gunnison Canyon at the Mouth of Wells Gulch

		Feet
1.	Sandstone in thin flinty layers separated by dark colored shale	20
2.	Coal	3
3.	Shale, carbonaceous	8
4.	Conglomerate, quartzitic, gray to buff (Dakota)	15
	[Base of Dakota and top of Morrison.]	
5.	Sandstone, conglomeratic, with beds of variegated shale. The conglomerate contains many pebbles of qartz and jasper	100
6.	Shale, variegated	175
7.	Sandstone, white, argillaceous	5
8.	Shale, soft, variegated; contains pockets filled with pebbles of jasper, chert, argillite, etc.; also globular lenticular bodies of pink to red calcite, having a maximum diameter of 5 feet	200
9.	Sandstone, gray, coarse-grained, cross-bedded.	50
10.	Sandstone, brown, massive	8
11.	Shale, pink	10
12.	Sandstone, brown, massive	15
13.	Shale, sandy	10
14.	Sandstone, flinty	4
15.	Shale, variegated	30
16.	Shale and limestone, evenly bedded	25
17.	Shale and sandstone in thin regularly bedded layers	50
	Unconformity by erosion.	
18.	Sandstone (red beds)	(?)
		728

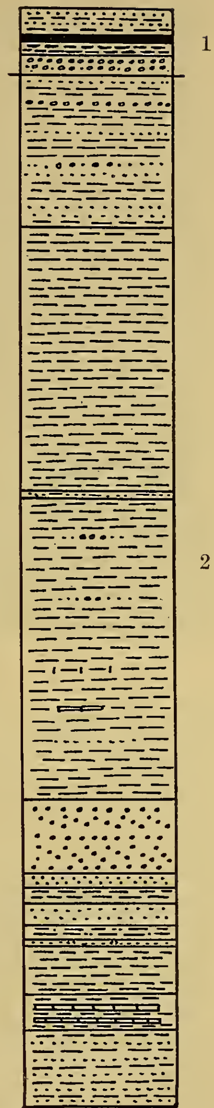

FIG. 26.—*Section of the Morrison formation in Gunnison Canyon at the mouth of Wells Gulch, Colorado.*

1.—Dakota; 2.—Morrison. Scale, 125 feet to 1 inch. (Lee.)

The Morrison (McElmo) formation is very well exposed a few miles southwest of Mack, where the Grand River makes a sharp turn and where a tributary cuts directly across the strata. The bend in the river cuts directly across a large monoclinal fold, exposing the underlying beds. Good exposures occur for considerable distances, and it is possible to make a complete section of the formation at a number of points. The chief characteristic of the formation in this district is the presence of a number of heavy, white, cross-bedded sandstones, which stand out as prominent ledges. Sandstones

FIG. 27.—*Morrison formation south of Grand Junction, Colorado, looking west.*

FIG. 28.—*Grand Mesa, south of Grand Junction, Colorado, looking south. Morrison outcrops in the foreground.*

FIG. 29.—*Morrison formation south of Grand Junction, Colorado, looking north.*

are especially characteristic of the lower portion of the formation, but heavy beds occur at intervals up to the top. A bed of limestone 2 feet thick is also present in the lower portion. The following section was measured by the writer in 1914:

Section of McElmo Formation near Mack, Colorado

	Feet
33. Dark, arkosic sandstone, taken as base of the "Dakota"............	2
32. Clay	34 e.
31. Sandstone	3
30. Covered	5
29. Cross-bedded white sandstone..................................	11
28. Clay	40
27. Cross-bedded white sandstone..................................	11
26. Clay	9
25. Lumpy clay..	1
24. Variegated clays..................................	52
23. White sandstone of varying size of grain..........................	3
22. Green sandstone, in places conglomeratic..........................	2
21. Clay, greenish at top..............................	16
20. *b*. Sandstone	3
a. White clay..	9

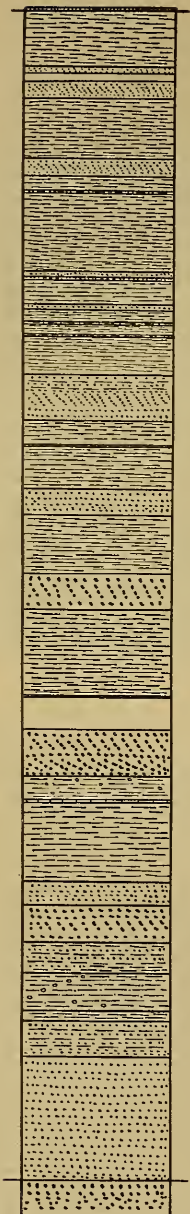

FIG. 30.—*Section of the Morrison formation near Mack, Colorado.*

The overlying formation is the "Dakota," and the underlying is the La Plata sandstone. Scale, 125 feet to 1 inch. (Section by the writer.)

		Feet
19.	Red sandstone or shale	1½
18.	*c.* Clay, white at top	7
	b. Red shale	1
	a. Clay	25
17.	White, coarse, cross-bedded sandstone with clay and shale members near the top	30
16.	*c.* Clay	16
	b. Sandy, compact clay	1
	a. Clay	27½
15.	White, cross-bedded sandstone	17
14.	Clay	30
13.	Heavy, cross-bedded sandstone	23
12.	Clay, may cover sandstone or nodule layers	57
11.	Sandstone	1
10.	Covered	22
9.	Heavy, cross-bedded sandstone	31
8.	Variegated clay with lumps, especially at top	16
7.	Limestone	2
6.	*c.* Clays	52
	b. Sandstone	15
	a. Cross-bedded sandstone	25 e.
5.	Sandstones and clays alternating. Mostly sandstones in beds 1–2 feet thick. Sandstone sometimes dies out and is replaced by clay, with or without nodules	20
4.	Red sand clay with nodules	25
3.	Gray shale	7
2.	White sandstone with some clay	24
1.	Pinkish white sandstone	80
	Total	766

The Morrison is underlain by the La Plata sandstone in most of the southwestern Colorado areas, with apparent conformity. Beneath the La Plata, which is Jurassic in age, there is a well marked stratigraphic break. At different localities the La Plata lies upon the Dolores beds, of Triassic age, upon the Cutler and Hermosa formations, of late Paleozoic age, and upon pre-Cambrian crystallines (Cross and Larsen, 1914, 7).

The McElmo formation near Green River, Utah, has been recently described by Lupton (1914, 3). It is from 1000 to 1200 feet thick at this place. Marine fossils in the lower part indicate, however, that part of the beds included in Lupton's section may belong to the underlying Jurassic beds.

The section is as follows:

FIG. 31.—*Monoclinal fold near Mack, Colorado.*

The Morrison beds are seen to the left, resting on the La Plata sandstone in the center.

FIG. 32.—*Outcrops of the Morrison formation near Mack, Colorado.*

The section shown in fig. 30 was taken at this point.

	Feet	Inches
Sandstone, gray, weathers brown; contains clay-ball concretions in places	8	..
Clay, bluish gray; contains a little limestone about 5 feet below top	28	6
Clay, brick red, gray and purplish, sandy; contains several thin beds of gray to white sandstone	116	..
Sandstone, gray; weathers brown; indurated at base, conglomeratic and quartzitic in places, lenticular	5	..
Clay, brick red, sandy	52	..
Sandstone, brick red, massive	14	..
Clay, brick red, sandy	12	..
Sandstone, gray, conglomeratic; contains some interbedded gray sandy shale	58	..
Sandstone, reddish, calcareous	17	..
Sandstone, gray to white, soft, cross-bedded in places	10	..
Sandstone, red and gray, soft, calcareous	42	..
Sandstone, gray to white, soft, massive; contains a little argillaceous material	37	..
Sandstone, grayish brown, interbedded with gray and reddish calcareous and argillaceous sandstone	27	..
Sandstone, white, weathers reddish brown	12	..
Sandstone, red with streaks of green, calcareous	20	..
Sandstone, grayish brown, with calcareous layers	50	..
Sandstone, brown	2	..
Sandstone, calcareous	5	..
Sandstone, grayish brown, medium bedded	4	..
Sandstone, red below and gray above, very calcareous; contains many small nodules	40	..
Sandstone, brick red, thin and medium bedded. This sandstone is believed to be calcareous. It bears manganese ore in the upper part	128	..
Sandstone, red, massive	400±	..
	1,087½	

NORTHEASTERN UTAH AND NORTHWESTERN COLORADO

The Flaming Gorge formations in northwestern Colorado and northeastern Utah have been described by H. S. Gale (1910, 6) as dark-greenish shales and sandstones, with fossils. Above the fossiliferous beds are 75 feet of dark thin-bedded, ripple-marked sandstone. This part of the Flaming Gorge represents the marine Jurassic which is characteristically represented in Wyoming by the Sundance formation. Above the marine beds are 650 feet of varicolored beds, usually of light pink and green. The Carnegie Museum of Pittsburgh has been operating a dinosaur quarry in these beds near Jensen, Utah. The beds in this vicinity are largely dark colored variegated clays, with interspersed layers of coarse sandstone of moderate thickness. The sandstones are resistant to erosion, and the beds dip steeply toward the west. The sandstones cap ridges underlain by the softer clays, making a series of parallel or con-

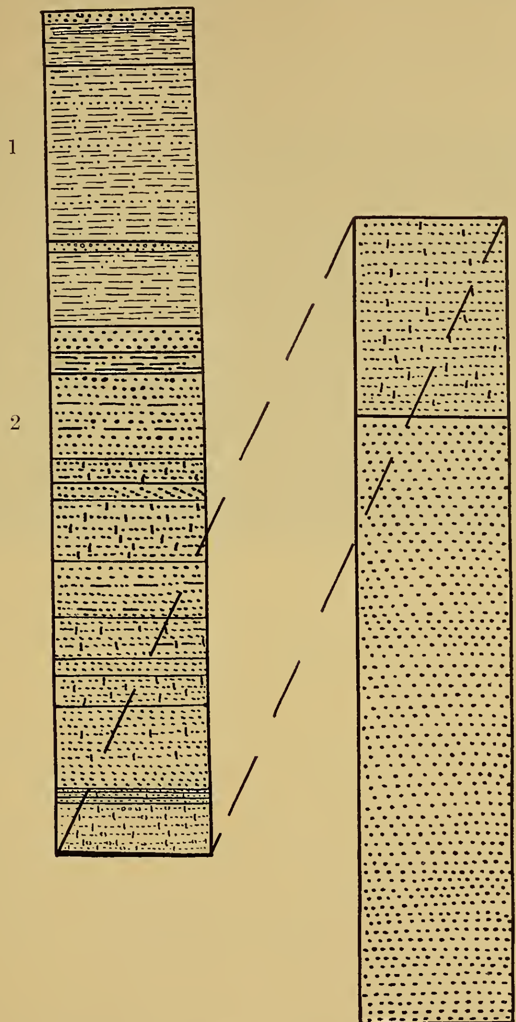

Fig. 33.—*Section of the McElmo formation near Green River, Utah.*
This section probably includes more than Morrison, as marine Jurassic fossils have been found in the base. Scale, 125 feet to 1 inch. (Lupton.)

centric hog-backs, the outer one of which is capped by the "Dakota" sandstone. The contact of the marine and non-marine beds is obscure and difficult to determine at the site of the Carnegie Museum's quarry.

FIG. 34.—*Outcrop of the Morrison formation near Jensen, Utah.*

MORRISON FORMATION IN MONTANA AND WYOMING (EXCEPT THE BLACK HILLS AREA)

CENTRAL AND SOUTHERN MONTANA

The Morrison formation has not been mapped or described from many localities in Montana. It occurs in the Great Falls coal field and neighboring localities and around the northern end of the Bighorn Mountains. It probably occurs elsewhere, but either has not been mapped, has not been separated from the Kootenie, or is buried beneath younger formations. The relation of the Kootenie to the Morrison, and its lithological similarity, may possibly indicate that the Kootenie may be in part equivalent to some parts of the Morrison.

The Morrison occurs in the Electric coal field, and has been described by Calvert (1912, 2). Calvert gives the following section:

	Feet	Inches
Sandstone, brownish, soft, capped by 1 foot of intrusive..........	23	
Shale, variegated, and sandstone, alternating, the latter reddish brown	65	..
Intrusive	..	8
Shale, purplish and maroon, alternating with thin reddish-brown sandstone	79	..

	Feet	Inches
Sandstones, thin, and sandy shale, with 2 feet of brown sandstone at top	18	..
	185+	8

The Morrison in this locality lies over the Ellis limestone, corresponding to the Sundance beds of Wyoming. There is a break below the Ellis, indicating an erosion period of considerable length.

In the Great Falls region the Morrison has been described by Fisher (1907, 3; 1909, 11; 1909, 13). He gives the following brief description of the outcrops of the Morrison: "The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying rocks of the Kootenie formation. It outcrops all along the base of the Little Belt Mountains from the east end of the district to Smith River. Good exposures occur along the upper courses of Sage, Skull, Running Wolf, Hazlett, Surprise, Geyser, and Otter creeks. and in the bluffs for some distance back from the mountains along Belt Creek, Sand Coulee, Smith River and its tributary, Ming Coulee." The Morrison rests with apparent conformity on the Ellis formation, which in turn rests unconformably on Carboniferous beds. The Kootenie overlies the Morrison conformably.

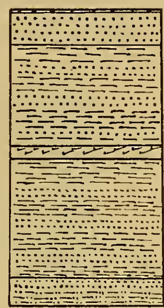

Fig. 35.—*Section of the Morrison formation in the Electric Coal Field, Montana.*

Scale, 125 feet to 1 inch. (Calvert.)

Fisher gives the following sections:

Section of the Morrison Formation on the east side of Belt Creek, Montana, in N. E. ¼ Sec. 30, T. 18 N., R. 7 E.

	Feet
Gray, thin-bedded sandstone	17
Pebbly conglomerate occurring in lenses	5
Maroon and green shale	52
Green shale capped by 1½ feet of gray sandstone	5
Calcareous sandstone, weathering light brown	5
Green shale	20
Massive sandstone, weathering light brown	7
Dark-green shale containing thin limestone layers	9
	120

Ellis formation.

Section of the Morrison Formation in the N. E. ¼ Sec. 3, T. 16 N., R. 10 E., near Shannon Creek, Montana

	Feet	Inches
Kootenie formation.		
Beds concealed	20	..
Shales, red and green, containing ironstone layers at base	46	..
Limestone, light colored, fossiliferous	5	..
Shale, green, sandy, fossiliferous	25	..
Limestone, white, fine-grained, thin-bedded	..	6
Shale, green, sandy	13	..
	109	6

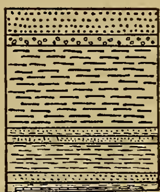

FIG. 36.—*Section of the Morrison formation on Belt Creek, Montana.* Scale, 125 feet to 1 inch. (Fisher.)

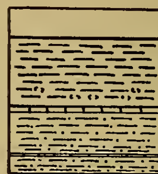

FIG. 37.—*Section of the Morrison formation near Shannon Creek, Montana.* Scale, 125 feet to 1 inch. (Fisher.)

BIGHORN MOUNTAINS

The Morrison formation is exposed along the eastern, northern and western sides of the Bighorn Mountains. The following description is taken largely from Darton (1906, 2).

The band of outcrops is almost a continuous one, except in a few localities where it is overlain by Tertiary deposits. Owing to the softness of the material of the formation, most of the outcrops are poor and are often covered with talus.

The thickness of the formation varies from 100 to 250 feet. West of Greub it is 160 feet, southwest of Buffalo 250 feet, northwest of Buffalo 150 feet, on Little Rapid Creek it is 200 feet, on Wolf Creek less than 100 feet, on Little Tongue River 120 feet, on Amsden Creek 150 feet, and about 150 feet or a little less on the northeastern side of the mountains in Montana. There is a considerable variation on the southeast side of the mountains. East of Barnum it is about 150 feet, east of Houck's 100 feet, near Griggs 200 feet, on the uplift south of Tisdel's ranch it is 250 feet. In the vicinity of Tensleep it is about 250 feet. On Alkali Creek, north of Cloverly, it is 282 feet, and in the region of Thermopolis, 120 to 130 feet.

Near Cloverly, where the dip is low, the outcrops cover large areas. In most localities the Morrison occupies a low saddle between the slopes of the Chugwater-Sundance ridge on the one hand and the hog-back of the Cloverly on the other.

The formation is mostly made up of hard clay or massive shale, varying in color from pale greenish to maroon, with darker clay at its summit. Several beds of light gray sandstone 2 to 20 feet thick are usually included. "These sandstones are usually soft, and on weathering exhibit thin, irregular bedding planes which generally have a peculiar wavy surface suggestive of incipient cross-bedding." There is apparently a conformable contact between the Morrison and Sundance beds. In the first

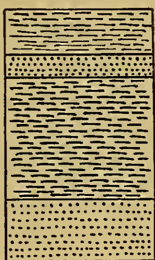

FIG. 38.—*Section of the Morrison formation on South Fork of Rock Creek, northwest of Buffalo, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

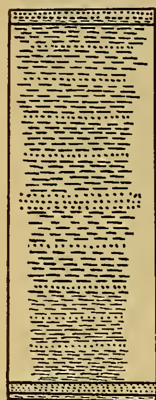

FIG. 39.—*Section of the Morrison formation on the south side of Muddy Creek, southwest of Buffalo, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

hollow south of South Fork of Rock Creek, northwest of Buffalo, the base of the Morrison consists of 40 feet of soft greenish-gray and pale-buff sandstones; then 80 feet of clays, 15 feet of the typical sandstone above described, and at the top 30 feet of clays, maroon, buff and greenish below and dark above. A mile south of Muddy Creek, southwest of Buffalo, there is an exceptionally good outcrop of the Morrison formation. It exhibits at the top 10 feet of reddish shale which grades down into dark shale, followed by 240 feet of hard, chalky clays of maroon and green color. This series of clays contains occasional thin sandstone partings, and one bed 6 feet thick near the middle. This bed is hard, light-colored, and weathers in thin beds with irregular wavy surface. Near the base of the series the clay is red. Next below is an 8-foot bed of white sandstone. Below this sandstone and resting on the Sundance beds are a few feet of soft gray and buff sandstones. On Little Poison Creek the characters are very similar to those on Muddy Creek. A mile north of Middle Fork of Crazy Woman Creek the section is as follows:

	Feet
Chalky clays, light green above, maroon below	80
Grayish-buff sandstone containing plants and saurian bones	6 to 12
Maroon and light green chalky clays with thin sandstone layers	70
White soft massive sandstone resembling the Unkpapa of the Black Hills region	12 to 15
Greenish sandy clays (may belong to the Sundance formation)	20
	188 to 197

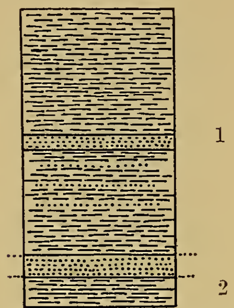

FIG. 40.—*Section of the Morrison formation north of Middle Fork of Crazy Woman Creek, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Darton.)

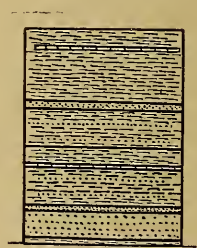

FIG. 41.—*Section of the Morrison formation near Beaver Creek, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

Near Beaver Creek the section is as follows:

	Feet
Light green to maroon chalky clays containing a 2-foot bed of limestone 10 feet below the top	50
Sandstone	4
Clays, in part maroon	25
Sandstone [thickness not given, probably very thin].	
Shale	10
Limestone with no fossils	1½
Red to maroon clays with thin sandstone layers	25
Thin-bedded sandstone	2
Soft, massive, white sandstone	20
Clays (a few feet).	
	137½+

South of Fort C. F. Smith, Montana, the following section occurs:

	Feet
Greenish-gray sandy shale, upper part soft (unconformably overlain by Cloverly sandstone)	18
Buff sandstone	5

	Feet
Massive gray sandstone	20
Variegated shale; pale red and green tints	75
Light colored, fine-grained, soft sandstone lying on brown sandstone of the Sundance formation	25
	143

The section near Tensleep is as follows:

	Feet
Gray shale capped by Cloverly sandstone	40
Greenish-gray clays	100
Maroon to red clays	50
Sandstone	58
Greenish-gray to reddish sandy shale	50
	298

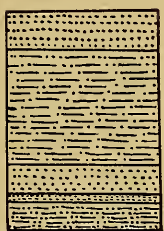

FIG. 42.—*Section of the Morrison formation south of Fort C. F. Smith, Montana.*

Scale, 125 feet to 1 inch. (Darton.)

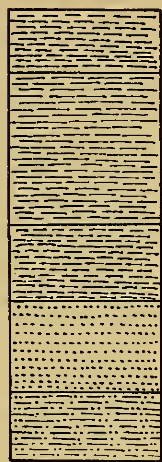

FIG. 43.—*Section of the Morrison formation near Tensleep, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

The following is a typical section of the Morrison on Alkali Creek:

	Feet
Pale green massive shale (overlain by Cloverly sandstone)	50
Thin-bedded gray sandstone, brown on surface	15
Pale green massive shale	5
Blue-black shale	10
Maroon massive shale	10
Variegated massive shale	45
Thin-bedded gray sandstone	6
Variegated massive shale, drab, purple and maroon	65
Pale green to white sandstone	6
Pale green and maroon massive shale	85
Pale green massive sandstone	45
Red sandy shale (lying on the Sundance formation)	40
	382

North of Thermopolis the formation contains, near its middle, a massive fine-grained, soft, greenish-gray sandstone 50 feet or more in thickness. Above this are 400 feet of sandy shales, some dark maroon in color, then 10 feet of very dark conglomerate loosely cemented, and at the top about 10 feet of highly carbonaceous shale merging into dirty-buff clay.

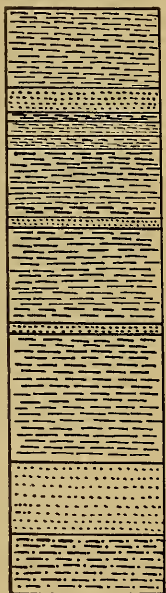

FIG. 44.—*Section of the Morrison formation on Alkali Creek, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

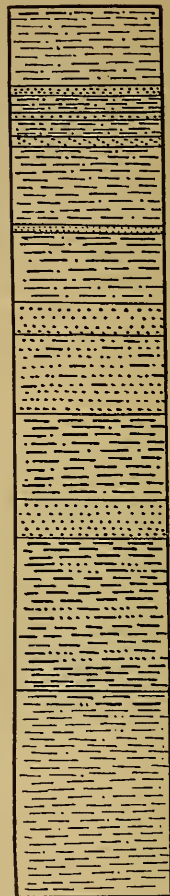

FIG. 45.—*Section of the Morrison formation on the Shoshone River, Wyoming.*

Scale, 125 feet to 1 inch. (Hewett.)

SHOSHONE RIVER REGION

The following section of the Morrison formation was made by Hewett, on the Shoshone River, Wyoming (1914, 2):

	Feet
Shale, maroon and gray, sandy	50
Sandstone, buff	6
Shale, gray, sandy	12
Sandstone, buff	4
Shale, gray, sandy	10
Sandstone, buff, cross-bedded	8
Clay, gray, sandy	50

	Feet
Sandstone, buff, fine-grained, evenly bedded and ripple-marked..........	6
Clay, maroon and yellow, sandy..	44
Clay, dark brown to black, containing saurian vertebræ, limb bones, and gastroliths	20
Sand, gray, argillaceous, only locally indurated, containing wood silicified in places, as well as rounded pebbles of similar material; carbonized plant remains and small calcareous concretions......................	50
Clay, maroon, sandy..	55
Sandstone, white, homogeneous, only locally indurated.................	25
Clay, prevailingly gray and olive colored, but with three broad maroon bands, sandy..	100
Shale, green sandy, transitional to upper sandstone of the Sundance formation	140
	580

CENTRAL AND SOUTHERN WYOMING

C. A. Fisher (1906, 4) describes the Morrison formation in the Absaroka and Owl Creek Mountain regions as follows:

"Along the western side of the basin [Bighorn] the Morrison formation is about 150 feet thick. It consists of alternating layers of gray fine-grained sandstone and dark-gray sandy shale. Near the base there is often a thin bed of gray limestone. In one locality near the southern end of the Cedar Mountain anticline a deposit of gypsum 8 feet thick was observed near the top of the formation." Fisher gives the following sections:

Section of Morrison Formation on Trail Creek, northwest of Cody, Wyoming

	Feet
Cloverly formation.	
Green, sandy shales alternating with green clay containing thin layers of gray limestone throughout..	100
Massive, fine-grained gray sandstone lying on Sundance formation.......	30
	130

Generalized Section of Morrison Formation south of Clark Fork Canyon, Wyoming

	Feet
Cloverly formation.	
Massive greenish-gray sandstone......................................	80
Greenish clay..	60
Dark gray limestone..	1
Dark gray sandy shale lying on Sundance formation....................	20
	161

Section of Morrison Formation near Watson's Ranch, on Embar Road, just north of Owl Creek, Wyoming

	Feet
Massive gray sandstone	10
Concealed material, evidently soft and sandy	125
	135

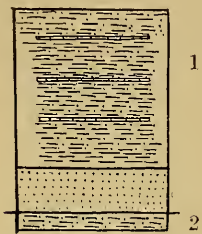

Fig. 46.—*Section of the Morrison formation on Trail Creek, northwest of Cody, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Fisher.)

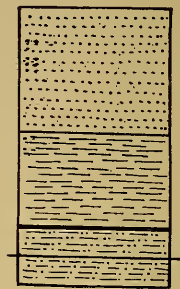

Fig. 47.—*Section of the Morrison formation south of Clark Fork Canyon, Wyoming.*

Scale, 125 feet to 1 inch. (Fisher.)

The following section of the Morrison formation in the Douglas oil and gas field, Wyoming, is given by Barnett (1914, 1):

Section of the Morrison and Sundance Formations in east bluff of North Platte River, in Sec. 9, T. 31 N., R. 71 W.

	Feet
Morrison formation:	
Shale, blue and red, with a 6-foot carbonaceous shale near top	180
Limestone, compact, fossiliferous	3
Sundance formation:	
Shale, blue and pink, calcareous and sandy, fossiliferous in lower part	60
Sandstone	10
Shale, bluish gray, with few bands of sandstone	60
Sandstone	12
Shale, bluish gray, sandy	30
Sandstone, gray, heavy bedded	75
	430

In central and southern Wyoming the Morrison formation has been well described by Darton (1908, 1). The formation outcrops along the eastern border of the Wind River Mountains, along both sides of the Owl Creek Mountains, on the north side of the Rattlesnake Mountains, in the Shirley and Freezeout Hills, south of Casper and Douglas and east of Medicine Bow and Rock Creek. It also occurs near Sheep Mountain, east of Jelm, and in the Centennial Valley. Outcrops occur on both the east and west sides of the Laramie Mountains. In the vicinity of Lander, the thickness of the formation is 225 feet, consisting mainly of pale green to maroon massive shales, with thin beds of sandstone. Near Fort Washakie it is 200 feet thick, and has a 4-foot sandstone bed near the middle. The thickness in the Owl Creek region varies from 100 to 250 feet, in general diminishing from east to west. In this region the formation consists principally of pale green sandy shale, with some darker tints. A thick bed of soft sandstone usually occupies the central portion. "In extensive exposures on the east side of Red Creek, 3 miles east of the summit of Black Mountain, the formation is about 150 feet thick." Darton gives the following section at this point:

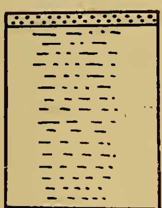

FIG. 48.—*Section of the Morrison formation near Watson's ranch on Embar road just north of Owl Creek, Wyoming.*

Scale, 125 feet to 1 inch. (Fisher.)

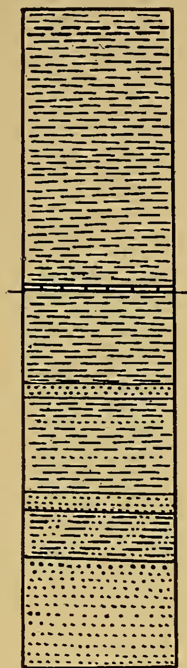

FIG. 49.—*Section of the Morrison and Sundance formations in east bluff of North Platte River, in sec. 9, T. 31 N., R. 71 W., Wyoming.*

Scale, 125 feet to 1 inch. (Barnett.)

	Feet
At the top, soft massive sandstones, mainly of buff color, also pink, lying on red and maroon clays	50
Red sandy clays, with a few sandstone layers from 6 inches to a foot thick	50
Massive sandy clays of alternating bands of gray and maroon	50
	150

The Morrison formation is well exposed in the vicinity of Medicine Bow. In Como Bluff, a few miles east of this place, a good series of outcrops occur, while on the opposite side of the anticline of which it forms the southern limb, another series of outcrops are less well exposed.

Dinosaur remains have been found in great abundance in this region, and a number of very productive bone quarries have been opened. The following section of Como Bluff is given by Darton:

	Feet
White, massive sandstone, conglomeratic (Cloverly).	
Bluish to greenish shales	50
Limestone, lumpy	1
Bluish to olive green shales	30
Limestone, lumpy	1
Blue and red shale	120
	202

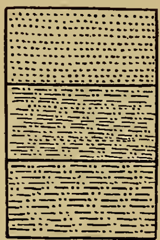

FIG. 50.—*Section of the Morrison formation on Red Creek, 3 miles east of Black Mountain summit, Owl Creek Mountains, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

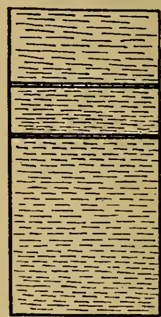

FIG. 51.—*Section of the Morrison formation in Como Bluff, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

Three sections in the north and south sides of the Como anticline and in the Medicine anticline or "Bone Cabin Draw" are given by Loomis (1901, 6) as follows:

Section on north side of the Como Anticline

	Feet
Dakota [Cloverly]	
Straw yellow sandstone	120+
Black sandstone	3
Yellow sandstone	12
Jurassic [Morrison and Sundance]	
Bluish-green clay	20
Green clay	40
Flint	1/3
Green clay	15
Concretions	2
Green clay	9
Green clay with small concretions	9
Maroon clay with small concretions	28
Green clay	20
Sandstone	2

	Feet
Green clay	9
Sandstone	2
Green, maroon, red clay	26
Sandstone	1½
Green clay	20
Sandstone	2
Green clay	60
Sandstone	1½
Maroon clay	20
Sandstone	1½
Purple clay with limestones	20
Brown clay with limestone beds	70
Total of Jurassic [Morrison and Sundance]	378 5/6

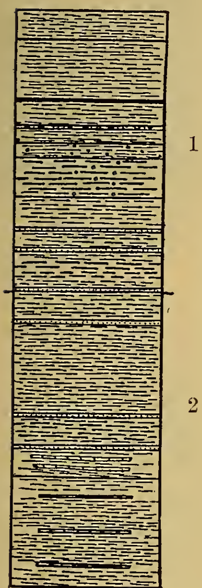

FIG. 52.—*Section of the Morrison and Sundance formations on the north side of Como Anticline, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Loomis.)

Section on south side of the Como Anticline, or Como Bluff

	Feet
Dakota [Cloverly]	
Sandstone	200+
Black and red sandstone	4
Straw yellow sandstone	20
Jurassic [Morrison and Sundance]	
Maroon clay	10
Bluish green clay	15
Yellow green clay	13
Bluish green clay	15
Sandy clay	5
Green clay	2
Concretions	1
Green clay	15
Sandstone	4
Green clay	10
Green clay with small concretions	25
Maroon clay with small concretions	20
Green clay	9
Red clay	5
Maroon clay	7
Red clay	8
Gray sandstone	28
Dark green clay	10
Sandstone	1½
Red and green clay	10
Sandstone	2
Green clay	25
Sandstone	12
Purple clay with limestones	15
Gray brown clay	55
Total of Jurassic [Morrison and Sundance]	332½

FIG. 53.—*Exposures of the Morrison formation in Como Bluff, Wyoming.* After Osborn.

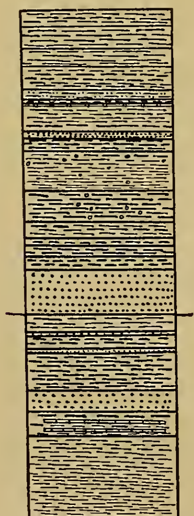

FIG. 54.—*Section of the Morrison and Sundance formations at Como Bluff, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Loomis.)

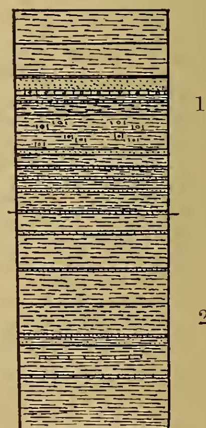

FIG. 55.—*Section of the Morrison and Sundance formations on the south side of Medicine Anticline, or "Bone Cabin Draw," Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Loomis.)

Section on south side of Medicine Anticline, or "Bone Cabin Draw"

	Feet
Dakota [Cloverly]	
Yellow sandstone	243
Black sandstone	2
Gray sandstone	30

Jurassic [Morrison and Sundance]	Feet
Bluish green clay	21
Green clay	20
Flint	1/3
Gray sandstone	10
Concretions	2
Green clay	3
Concretions	1½
Green clay	8
Green clay with concretions	10
Maroon clay with small concretions	10
Sandstone	3
Green clay	8
Sandstone	1
Red clay	5
Sandstone	2
Green clay	6
Sandstone	1½
Red, green, maroon clay	12
Sandstone	2
Maroon, green, red clay	10
Sandstone	2
Green clay	22
Sandstone	1
Green clay	20
Reddish clay	20
Sandstone	1½
Green sandy shale	6
Purple clay with limestones	22
Nucula limestone	1
Brown clay	43
Total of Jurassic [Morrison and Sundance]	274 5/6

In these sections the Morrison is interpreted as beginning with No. 13. The contact is not very distinct.

Logan gives the following section for the Freezeout Hills (1900, 5):

"Purplish clay containing considerable arenaceous inclusions.......... 40 ft.

"The clay contains, in the lower part, a thin stratum of sandy limestone in which the following fossils were found: *Pentacrinus asteriscus*, *Asterias dubium*, *Pseudomonotis curta*, *Avicula macronatus*, and *Ostrea strigilecula*.

"*The Atlantosaurus Beds*.—The last stratum is the last one containing marine fossils, and probably closes the Jura, but some of the non-fossiliferous beds lying above may belong to that formation. The succeeding stratum varies so much in thickness that it may represent the eroded surface of the Jura upon which the Atlantosaurus Beds were deposited.

"16. Fine-grained, grayish-white sandstone.................. 10 ft. to 125 ft.

"The above stratum varies much in thickness within short distances. At one point on the Dyer ranch it has a thickness of only 10 ft., while a few miles southeast it reaches a thickness of 125 ft. The sandstone composing the layer is of nearly uniform color and texture. Its induration is only moderate, and it weathers into many grotesque forms. Cross-bedding is well exhibited by it in many localities.

"17. Purple to greenish-colored clay.................................. 60 ft.

"This is apparently an unfossiliferous layer, except in the uppermost horizon, where species of dinosaurs belonging to the genera *Brontosaurus* and *Morosaurus* occur.

"18. Sandstone, grayish to light brown...................... 10 ft. to 20 ft.

"The above sandstone presents some very interesting stratigraphic phenomena. It has, at the base, a layer of conglomerate about 2½ ft. thick. The conglomerate is composed of small silicious and argillaceous pebbles, and is not very coherent. Something like two feet of sandstone rests upon the conglomerate; the bedding planes of the sandstone are oblique to the bedding planes of the beds above and below. Succeeding the sandstone above is 6 in. of sandstones in very thin layers, with lignitic seams along its horizontal but wavy bedding planes. The above is overlain by 4 in. of conglomerate, followed by 1 in. of sandstone with oblique bedding planes. Overlying this layer is a thin layer of sandstone in which the bedding planes are horizontal. The remainder of the stratum is made up of sandstone with the bedding planes as follows: One ft. oblique; then 3 in. horizontal; then 2 ft. oblique; and finally 3 in. horizontal. The stratum furnished in one place the trunk of a large fossil tree and a large number of fossil cycads. Fragments of fossil wood were found in a number of places, but cycads in only the one. Fragments of a hollow-boned dinosaur were found in one place in the horizon.

"19. Drab-colored clay.................................. 30 ft. to 40 ft.

"This stratum contains the bones of the large dinosaur, *Brontosaurus*. Otherwise it appears to be quite unfossiliferous.

"20. Fissile, brownish sandstone............................ 4 ft. to 5 ft.

"No fossils were found in this sandstone, and the most characteristic feature about it is its uniformly brown color. It seems to be moderately persistent, as its occurrence in many places in the hills was noticed.

"21. Bluish-green clay containing very small concretions.............. 30 ft.

"In the bone quarries of this horizon, which furnished species of *Brontosaurus*, *Morosaurus*, and *Diplodocus*, were found specimens of (*Planorbis*) *veternus* and *Valvata leei*. This is the lowest horizon at which any of these non-marine invertebrates were noticed. It is probable that they will be found lower down, as the dinosaurs occur much lower.

"22. Brown to bluish-gray arenaceous limestone................ 8 in. to 1 ft.

"This stratum contains the following non-marine invertebrate forms: *Unio knighti*, *U. baileyi*, *Valvata leei*, and (*Planorbis*) *veternus*. Species from the same genera have been described by Meek from a similar stratum of limestone in the Black Hills. As these occupy much the same stratigraphical position they are probably the same age. The *Lioplacodes* seem to be identical with that described by Meek in the Geology of the Upper Missouri.

"23. Drab-colored clay................ 70 ft.

"Species of the genera *Brontosaurus*, *Diplodocus*, *Morosaurus*, *Stegosaurus* and *Allosaurus* occur in this horizon. Portions of species of all these genera were found in one quarry by the Kansas University collecting party. The clay is of that quality usually designated as 'joint' clay. It contains in places iron and argillaceous concretions of small size. The iron, and sometimes the bones, are covered with selenite crystals.

"24. Grayish-white sandstone......... 50 ft.

"This layer forms a conspicuous capping for the hills, and is the highest remnant of the anticline. It breaks up into large blocks, which lie scattered along the slopes of the underlying softer beds. Its erosion and disintegration is accomplished chiefly by sapping. No fossils were found in this stratum, and its true position is in doubt."

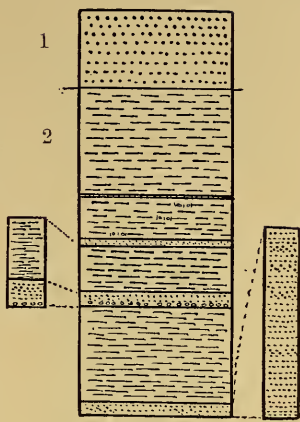

FIG. 56.—*Section of the Morrison formation in the Freezeout Hills, Wyoming.*

1. — Cloverly formation; 2. — Morrison formation. Scale, 125 feet to 1 inch. (Logan.)

The following sections are given by W. C. Knight (1900, 2):

Sioux Fault Section

Cretaceous:

Dakota conglomerate and sandstone.

Jurassic:

	Feet
1. Variegated marls and clays shading from dark yellow to dark maroon, with dinosaurian remains........................	38½
2. Calcareous sandstone......................................	2
3. Bluish and yellowish marls, containing *Brontosaurus* at top and *Morosaurus* at base......................................	22½
4. Drab calcareous sandstone................................	1½
5. Light colored clays and marls, with thin bands of sandstone...	24
6. Clays and marls varying from light gray to brown............	23½
7. Hard band of light gray clay................................	4½
8. Drab and greenish clays....................................	22½
9. Drab sandstone..	2
10. Yellow, greenish and light brown marls shading into maroon in the upper portion..	38½
11. Gray sandstones...	3
12. Bluish gray clay..	4
13. Bluish and drab clays interstratified with yellowish bands.....	38½
Total thickness of fresh-water beds [Morrison]..........	226
14. Variegated clays and marls with bands of sandstone...........	43½
15. Yellowish sandstone..	8½

	Feet
16. Dark shale beds with remains of *Baptanodon, Belemnites, Ostrea, Tancredia, Camptonectes* and a few Septaria..........	38½
17. Yellowish sandstone..	2½
18. Gray sandstone..	5½
19. Yellowish sandstone alternating with thin clay bands.........	6½
20. Thin bedded gray sandstones with a few bands of clay........	5½
Total [Shirley or Sundance]...........................	118

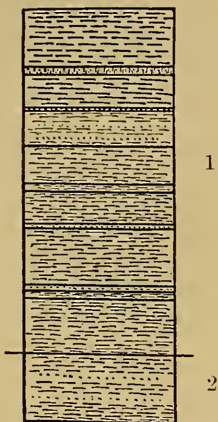

Fig. 57.—*Section of the Morrison formation at Sioux Fault, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Knight.)

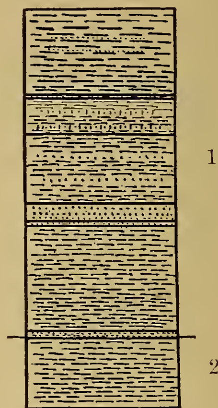

Fig. 58.—*Section of the Morrison formation in the Freezeout Hills, Wyoming.*

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Knight.)

Freezeout Hills Section

Cretaceous:

1. Dakota conglomerate.

Jurassic:

	Feet
2. Drab marls and clays with a few thin bands of light colored sandstone containing remains of Dinosaurs................	55
3. Hard clay and sand containing fresh-water molluscs and crocodiles	1½
4. Drab marls and clays with a few bands of calcareous sandstones with remains of *Allosaurus, Diplodocus, Brontosaurus, Morosaurus, Stegosaurus, Ceratodus* and Turtles................	24½
5. Drab marls and clays with thin beds of soft sandstone.........	46
6. Yellowish soft sandstone with cycads and petrified wood......	10
7. Brown sandstone, cross-bedded................................	2
8. Drab shales, clays and marls..................................	70
9. Greenish sandstone..	4
Total fresh-water beds [Morrison].....................	211

		Feet
10.	Reddish and brown shales and clays	49
11.	Dark fossiliferous limestone with *Camptonectes* and *Ostrea*	2
12.	Greenish shales with dark bands of clay and sandstone, with clay containing concretions of limestone rich in fossils. Fossils present: *Belemnites, Pentacrinus, Astarta, Grammatodon, Ostrea, Pseudomonotis, Pleuromia, Pinna, Lima, Megalneusaurus, Baptanodon* and *Plesiosaurus*	50
13.	Gray sandstone	4
14.	Red and brown shales with concretions and a few fossils	44
15.	White sandstone with upper band containing fossils	30
	Total marine beds [Shirley or Sundance]	179

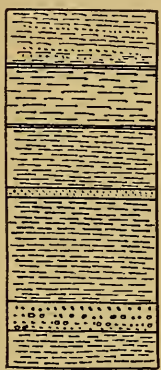

FIG. 59.—*Section of the Morrison formation at Red Mountain, Wyoming.* Scale, 125 feet to 1 inch. (Knight.)

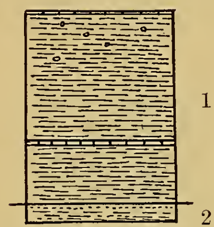

FIG. 60.—*Section of the Morrison formation at Red Mountain, Wyoming.*
1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Darton.)

Red Mountain Section

Cretaceous: Dakota removed but present in most instances.
Jurassic:

1.	Drab marls and clay with two thin bands of limestone and one of chert and chalcedony with Dinosaur remains	35
2.	Drab limestone	2
3.	Variegated marls with Dinosaur remains	38
4.	Gray limestone	1
5.	Drab marls and clays	39
6.	Gray sandstone	6
7.	Drab marls and clays	69
8.	Gray sandstone and some conglomerate	20
9.	Drab and red marls and clays	25
	Total, all fresh-water beds	235

Darton (1908, 1) gives the following section at Red Mountain:

	Feet
Bluish shales	40
Limestone	1
Bluish shales	50
Limestone	2
Bluish shales	36
	128

"The Morrison formation outcrops on the west bank of Laramie River just below the ridge a mile northwest of Laramie. There are 3 feet of dark shale at base, then 20 feet of soft, massive light colored sandstone, and at top 10 feet of gray shale with several thin, slabby limestone layers, one of which is pebbly, and a thin layer of gray sandstone. In slopes 1½ to 2 miles south-southwest of Howell station are soft, massive buff

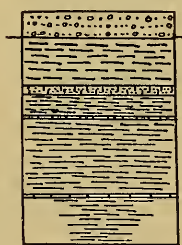

Fig. 61.—*Section of the Morrison formation on the east slope of the ridge west of Downey Soda Lakes, Wyoming.*

1.—Cloverly; 2.—Morrison. Scale, 125 feet to 1 inch. (Darton.)

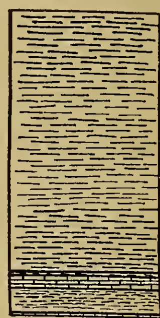

Fig. 62.—*Section of the Morrison formation on the South Fork of Horse Creek (east of the Laramie Mountains), Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

sandstones overlain by typical gray and greenish gray massive shale or clay with thin limestone, cherty, and sandstone layers. One of the latter is 2 to 3 feet thick. At the top are very dark shales, which have been prospected for coal; these are overlain by coarse Cloverly sandstone" (Darton, 1908, 1).

Darton also gives the following section of the Morrison formation on the east slope of the ridge west of Downey Soda Lakes:

	Feet
Cloverly sandstones and shales.	
Drab to olive green shale	30
Soft, coarse-grained, disintegrated sandstone, with calcareous matrix, containing teeth and bones	6
Drab to blue shale	15

	Feet
Nodular limestone	1–2
Blue shale	50
Limestone	2
Concealed, probably blue shale	30+
	135+

On the east side of the Laramie Mountains Darton (1908, 1) describes the Morrison in the first canyon south of South Fork of Horse Creek as consisting of the following: pale green and maroon massive shale on 30 feet of light colored massive shale which contains several limestone layers, one being 6 feet thick. "On South fork of Horse creek, the 6-foot limestone member is conspicuous, underlain by 20 feet of gray shale lying on a 1-foot limestone bed at supposed base of formation. The total thickness here is about 200 feet, which appears to be the average amount, except on the southernmost prong of Horse creek, where it is less than 150 feet."

Morrison Formation in the Black Hills Area

The Morrison formation occurs in the Black Hills area in eastern Wyoming and western South Dakota. It is present in the hog-backs surrounding the central area of the Black Hills. Outcrops are present around almost the entire circumference. For a short space on the southeastern side it is absent, however, the Lakota sandstone lying directly upon the Unkpapa sandstone. The significance of the absence of the formation at this point will be discussed later. The Black Hills Morrison is usually underlain by a reddish, banded, porous sandstone, known as the Unkpapa; in some areas, however, it rests directly upon the Sundance beds. The thickness of the formation in the various sections that have been measured are as a rule less than the thickness in the various central Wyoming areas and much less than the areas in western Colorado.

The following general description of the Morrison and Unkpapa formations in the Black Hills area is from Darton (1909, 5). Detailed descriptions of the formation in various quadrangles will be given later.

The Unkpapa sandstone has been fully described by Darton. This formation is a characteristic one in the Black Hills region. It is more extensively developed in the southern than in the northern part of the area. In the northwestern and western part of the region it consists of a thin yellowish sandstone. In the southern and southeastern part of the area it is represented by uniform-textured, fine-grained sandstone of varying colors. The following thicknesses are given by Darton: near Sturgis, 60 to 70 feet; near Tilford and Piedmont, 40 feet; south of Rapid, 30 to 50 feet; a mile north of Rapid, 150 feet; in the Bellefourche region, 10 to 30 feet (not clearly separated from the Sundance); very thin in the Aladdin and Sundance regions. It is usually clearly separable from the Sundance below and the Morrison above.

The Unkpapa is usually soft, white, buff, red or purple in color; it contains considerable material, and is often strongly banded. This banding is usually parallel with the bedding, but occasionally makes a marked angle with it. The rock is extremely porous and often exhibits interesting examples of microfaulting in hand specimens.

The name "Beulah shales" has been applied to the Morrison of the Black Hills region. The formation consists of the usual series of clays and shales, with thinner layers of sandstone and calcareous nodules. The prevailing color is gray, but other colors, such as red, maroon, pink and purple sometimes occur. Carbonaceous matter is sometimes present in the upper members. The following thicknesses of the Black Hills Morrison are given by Darton: near Rapid, 165 feet; east of Piedmont, 220 feet; rapidly decreasing to 70 feet in nearby locality; 4 miles north of Tilford, 110 feet; 1 mile south of Rapid, 90 feet; 3 miles south of Rapid, 165 feet; in the region about Sundance, 150 feet; at Aladdin, 60 feet; east of Aladdin, 80 feet or more; in Redwater Valley southwest of Bellefourche, 50 feet; near Lookout Peak, 100 feet; about Table Mountain and north of Eothen, 150 feet; near Alva, about 100 feet; in Barlow Canyon, 85 feet; 3 miles north of Hulett, 150 feet; on Miller Creek, 7 miles southeast of Devils Tower, 160 feet. The thinnest section recorded is in Barlow Canyon north of Devils Tower, the thickness there being 40 feet. Dinosaur bones of great size have been found in the Morrison near Piedmont, apparently belonging to a sauropod of great specialization, resembling *Diplodocus*.

In the Newcastle quadrangle the Morrison deposits are mostly of light gray color, but some portions are buff, pale green and maroon. The thickness averages a little more than 150 feet and is greatest in the northern part of the quadrangle. The beds outcrop along the inner side of the hog-back below the Lakota conglomerate and sandstone. In the region east of Salt Creek they occur in extensive outliers overlain by protecting caps of Lakota, and in the sloping plateau north of Newcastle they are revealed in the deep canyons. The outcrops are often obscured by talus derived from the sandstone cliffs above and by wash along the slopes. The *contact with the Sundance shows an abrupt change in the character of the material.* At Cambria a drill hole in the floor of the coal mine penetrated 12 feet of sandstone with coaly layers at the base of the Lakota and passed through the following beds, probably all of which belong to the Morrison (Darton, 1904, 4):

	Feet
Fire clay, gray	3
Sandstone, light gray, moderately hard	1½
Fire clay	7½
Sandstone, gray, upper half very hard	4
Shales, lead colored, soft at base	11
Shale and fine sand	3
Shale, bluish gray	18
Sandstone, moderately hard	1
Clay, bluish and purplish, hard below	20

The Morrison formation in the Aladdin quadrangle has been described by Darton and O'Harra (1905, 6). It is a thin but persistent deposit of massive shale between the Sundance and Lakota formations. Its color is generally a characteristic pale olive green, with local bands of gray and maroon. In fresh exposures some of the beds are darker and in some localities portions of the deposit are black. "The thickness is variable, owing to local unconformity on its surface, and its measure is difficult to determine at most localities owing to talus and landslides along the base of cliffs of Lakota sandstone." The shale includes thin beds of sandstone, most of which is fine-grained and light in color. Nodules of hard clay occur in some of the beds. The formation outcrops extensively along both slopes of the northern extension of the Bear Lodge Mountains and outlying ridges; in the ridge between Deer and Medicine creeks; in the basins at the heads of Pine, Alum and Hay creeks; in ridges north and south of Aladdin; and in the anticline east of The Forks.

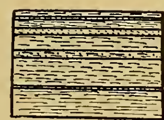

FIG. 63.—*Section of the Morrison formation in drill hole in floor of coal mine at Cambria, Wyoming.*

Scale, 125 feet to 1 inch. (Darton.)

Darton and Smith (1904, 5) have described the Morrison formation in the Edgemont quadrangle. In this quadrangle the Morrison consists of massive shales and clays, partly light gray and partly red or maroon, with occasional layers of fine-grained white sandstone. West of Minnekahta the thickness is about 100 feet, but eastward, northwest of Cascade Springs, the formation thins and dies out completely. Just west of Cascade Springs the Lakota lies directly upon the Unkpapa sandstone. The Morrison is exposed in the upper part of the slope at the base of Lakota cliffs in the northern face of the hog-back westward. As the dip is low and the formation is relatively thin, the outcrop is somewhat irregular. The formation is exposed in Hell and Falls canyons and in the canyon south of Parker Peak, lying on the Unkpapa sandstone. In Hell Canyon the formation extends to within about a mile of the Cheyenne River. It is variable in thickness at this point and consists mainly of gray and red sandy clay. On the west side of Falls Canyon the formation is about 60 feet thick, greenish at the base, darker above, and light green and maroon in its upper portion; on the east side it thins to about 20 feet.

There are exposures of the Morrison in Chilson Canyon a mile southwest of Chilson, and in the heads of branches of Bennett Canyon, where it is pale greenish, massive clay, with thin, white, fine sandstone members 3 to 10 inches thick. It is also cut through by Cheyenne River east of Edgemont. In an exposure in Red Canyon, where the formation is 80 feet thick, there is a thin limestone layer containing remains of algæ at the base. In a well at Edgemont the formation appears to be about 150 feet thick. "In the western part of the quadrangle the Morrison shale is distinctly separated from the Sundance formation, and in the eastern part from the Unkpapa sandstone, by an abrupt change in character and material, but there is no evidence of erosional unconformity."

The Morrison in the Sundance quadrangle has been described by Darton (1905, 5). The formation here shows the usual light gray and maroon colors, with buff and purple. It contains thin beds of sandstone and occasional layers of limestone. The average thickness is about 150 feet. The outcrops form a zone extending across the western and southwestern parts of the quadrangle. The deposits are distinguished from those of the Sundance by the color and massive texture of the shale. The most outcrops are in the ridges adjoining Beaver Creek, along Mason Creek, in Skull Creek Valley north and west of the Holwell ranch, in Black Canyon, along Oil Creek and in Oil Creek Valley.

The following sections of the Morrison formation in the Black Hills region are given by Darton, from O'Harra (1909, 5):

Section of Morrison Formation on north side of Sourdough Creek, 6 *Miles north of Hulett, Wyoming*

	Feet
Shale, yellow at top, red at bottom	18
Black shale	14
Black shale with 4-inch sandstone near top, slight purple or pink tinge throughout and rather conspicuous near the middle	17
Black shale	26
Slightly sandy green soft shale; some lime nodules near base	10
White sandstone	2
Green shale	5
White sandstone, carbonaceous streaks	2
Gray and reddish shales	40
	134

Section of Morrison Formation on Ridge south of Lytle Creek, 8 Miles southeast of Devils Tower, Wyoming

	Feet
Argillaceous limestone	2
Concealed	3
Argillaceous limestone	1
Grayish soft shale	12
Argillaceous limestone	1
Yellowish-gray shale	6
Argillaceous limestone	1
Greenish shale	40
Argillaceous limestone	½
Greenish shale	30
	96½

The upper and lower contacts are not clearly shown at this place.

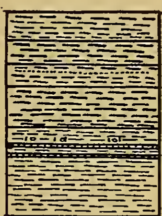

FIG. 64.—*Section of the Morrison formation on north side of Sourdough Creek, 6 miles north of Hulett, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

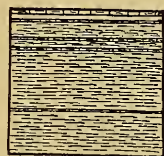

FIG. 65.—*Section of the Morrison formation on ridge south of Lytle Creek, 8 miles southeast of Devil's Tower, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation on prominent Lakota-capped Hill, 4 Miles east-southeast of Devils Tower, north of Lytle Creek, Wyoming

	Feet
Impure fire clay, containing rough nodular layer	2
Fine green shale	12
Sandy fire clay	1
Fine green shale, locally with purple tinge	70
Lime-clay shale	6
Fine green and drab shale	12
Green shale with some lime-clay nodules	16
Limestone, slightly argillaceous	6
	125

Section of Morrison Formation on north side of Deer Creek, 10 Miles northeast of Hulett, Wyoming

	Feet
Dark purple shale, weathers to light purple	9
Massive sandstone	1

	Feet
Purple shale	10
Concealed	8
Purplish-gray shale	12
Dark purplish shale	20
Very dark shale	14
Gray shale	17
Concealed; contains some sand	24
Green and purple shale	6
Sandy shale	4
White sandstone, weathering to a dirty velvety brown	1
Grayish-white shale	5
Green shale	2
Fissile purple shale	6
Grayish-green shale with some lime nodules	16
	155

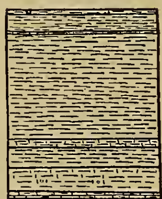

Fig. 66.—*Section of the Morrison formation 4 miles east-southeast of Devil's Tower, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

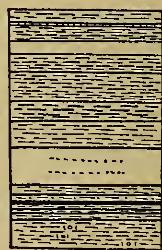

Fig. 67.—*Section of the Morrison formation on north side of Deer Creek, 10 miles northeast of Hulett, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation near head of Burnt Hollow, 4 Miles northwest of Hulett, Wyoming

	Feet
Very black shale, resembling a coal outcrop on weathered surface; may possibly represent the horizon of the Aladdin coal	10
Gray shale	32
Sandstone	1
Shale with poorly preserved plant impressions	3
Interbedded shales and thin sandstones	18
	64

Section of Morrison Formation a short Distance east of the foregoing Section

	Feet
Very black shale, as in above section	10
Brownish-gray and purple shale	14
Sandstone	2
Brownish-red shale	8

	Feet
Black shale	40
Light gray shale	36
	110

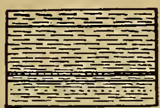

FIG. 68.—*Section of the Morrison formation near head of Burnt Hollow, 4 miles northwest of Hulett, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

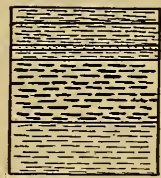

FIG. 69.—*Section of the Morrison formation a short distance east of the foregoing section.* (Fig. 68.)

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation on north side of Moores Canyon, 2½ Miles northwest of Hulett, Wyoming

	Feet
Grayish-purple shale	20
Dark purple shale	36
Yellowish, slightly sandy shale	4
Nodular layer	1
Dark greenish-gray shale	10
Nodular layer	1
Purple shale	6
Dark gray shale with lime-clay nodules	2
Drab shale	8
Very soft sandy shale	8
	96

Section of Morrison Formation 2½ Miles west of Belle Fourche River

	Feet
Purple, gray and yellowish shale with one or two thin sandstones	60
Flaggy to massive white sandstones	4
Purple and green shale with a few limestone nodules	60
	124

Section of Morrison Formation 3 Miles south of Rapid Gap, South Dakota

	Feet
Concealed to base of Lakota sandstone	20
Mostly green shale, partly concealed	40
Dark green shale, weathering into small fragments	6
Massive gray sandstone	5

	Feet
Green and purple massive shale, with some sand; iron stains	12
Soft thin sandstones	2
Green sandy shale	2
Soft sandstone, green and gray	12
Green shale with some sand	12
Purple shale	4
Calcareous nodular layer.	
Massive shale, green and purple	2
Purple shale, with calcareous nodular layer	4
Calcareous nodular layer	1
Massive shale, green and purple	3
Massive but soft sandstone; light red and brown at bottom, but mostly white; slightly brecciated near the top and containing some calcite	20
Massive red shale with some sand	12
Massive shale with calcareous nodules, purple and yellowish	5
Soft bright red argillaceous shale	3
	165

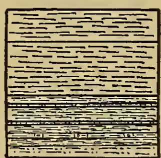

FIG. 70.—*Section of the Morrison formation on north side of Moores Canyon, 2½ miles northwest of Hulett, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

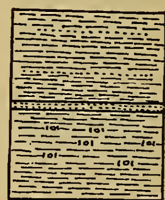

FIG. 71.—*Section of the Morrison formation 2½ miles west of Bellefourche River, Wyoming.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

The following sections of the Morrison formation in the Black Hills region are given by Loomis (1902, 7):

Section on Bellefourche River, Wyoming

	Feet
Olive green clay	70
Yellow-green clay with small concretions	12
Maroon clay	10
Green clay	6
Limestone concretions	1
Green clay	6
Maroon clay with small concretions	6
Green clay with small concretions	10
Limestone concretions	1
Green clay	4
Limestone concretions	1

	Feet
Green clay	6
Soft yellow sandstone	2
Green clay	7
Soft yellow sandstone	2
	144

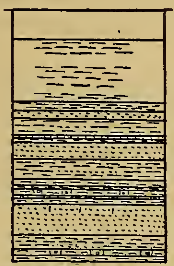

FIG. 72.—*Section of the Morrison formation 3 miles south of Rapid Gap, South Dakota.*

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

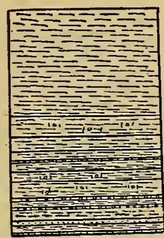

FIG. 73.—*Section of the Morrison formation on the Bellefourche River, Wyoming.*

Scale, 125 feet to 1 inch. (Loomis.)

Section on Inyan Kara Creek

	Feet
Olive green clay	40
Light green clay	12
Maroon clay with small concretions	10
Green clay with small concretions	5
Red clay	5
Green clay	5
Maroon clay	6
Green clay	20
Limestone concretions	1
Yellow sandstone	9
Dense gray sandstone	8
Yellow sandstone	5
Limestone concretions	1
Yellow sandstone	12
	139

Section at Sheldon Post Office

	Feet
Olive green clay	30
Limestone concretions	1
Green clay	10
Maroon clay	5
Yellow-green clay	9
Red clay	5
Limestone concretions	..

	Feet
Green clay	8
Limestone concretions	1
Red clay	3
Green clay	12
Limestone concretions	1
Green clay	12
Gray sandstone	2
	99

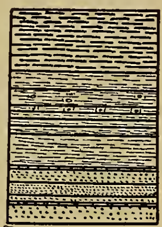

Fig. 74.—*Section of the Morrison formation on Inyan Kara Creek, Wyoming.*

Scale, 125 feet to 1 inch. (Loomis.)

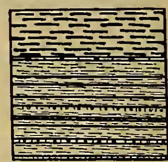

Fig. 75.—*Section of the Morrison formation at Sheldon Post-office, Wyoming.*

Scale, 125 feet to 1 inch. (Loomis.)

Section at Kara Peak

	Feet
Red clay	3
Green clay	3
Cream sandstone	8
Blue-green clay	6
Red clay	1
Limestone concretions	1
Purple clay	3
Red clay	2
Cream sandstone	2
Green clay	3
Cream sandstone	2
White sandstone	11
Black clay	2
White sandstone	8
Yellow sandstone	75
Slate green clay	50
Gray sandstone	15
	195

Section at Beaver Creek

	Feet
Brown-green clay	15
Olive green clay	66
Green clay with small concretions	15

	Feet
Maroon clay with small concretions	6
Green clay	15
Maroon clay with small concretions	12
Green clay	6
Limestone concretions	1
Olive green clay	8
Buff sandstone	12
	111

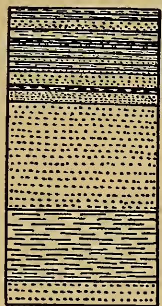

Fig. 76.—*Section of the Morrison formation at Kara Peak, Wyoming.*

Scale, 125 feet to 1 inch. (Loomis.)

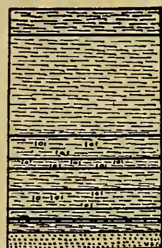

Fig. 77.—*Section of the Morrison formation on Beaver Creek, Wyoming.*

Scale, 125 feet to 1 inch. (Loomis.)

Atlantic Coast Representative of the Morrison Formation

ARUNDEL FORMATION OF MARYLAND

The Morrison formation is apparently represented in the eastern part of the United States by part of the Potomac series. It was formerly claimed that the Potomac was a unit formation. Its age has been discussed by a number of workers, some holding it to be Jurassic, others Cretaceous. More recently it has been divided into several distinct formations, separated from one another and from the underlying and overlying formations by disconformities or stratigraphic breaks. The lowest formation of the Potomac series, the Patuxent, contains none of the dinosaurian fauna characteristic of the Morrison, but the middle member, or Arundel, is characterized by many forms identical with or closely related to the forms of the Morrison fauna. The Arundel beds have been well described by Clark, Bibbins and Berry (1911, 5).

The Arundel is the lower part of the "upper oölite," or "Iron-Ore Clays" of Tyson, a part of the "Variegated Clays" of Fontaine and McGee, and of the "Baltimorean" of Uhler. It is the equivalent of the "Iron-Ore series" of Ward. It outcrops in an irregular northeast-southwest belt, from the head of Bush River, in Hartford County, to Washington, D. C.

The Arundel consists typically of drab, more or less lignitic clays, with masses of siderite. The nodules and geodes of siderite, when exposed to the air, often change to brown hematite. The clays are usually free from grit, but are occasionally sandy, and in places carry pyrite and gypsum. Lignite beds also occur.

The thickness of the formation is not great, the maximum being about 125 feet, and usually it is much less than that. It is thickest on the western side or middle of the belt, and thins eastward as shown by borings.

The Arundel overlies the Patuxent disconformably, and appears to occupy old drainage lines in the Patuxent. Cross-bedding is occasionally found in the lower beds, but is not usually present. The formation is overlain, with disconformity, by the Patapsco formation. The fauna will be discussed in the section on the age of the Morrison formation.

Summary of Stratigraphic Relations and Characters of the Morrison Formation

The stratigraphic relations and characters of the Morrison are summarized in the following pages.

Distribution

The Morrison formation has a wide distribution in Utah, New Mexico, Colorado, Wyoming, Montana, South Dakota and perhaps Idaho and Arizona. The number of square miles of Morrison outcrops is not very great, but the area in which the Morrison is overlain by younger deposits probably includes several hundred thousand square miles. The areas from which the Morrison has been eroded probably includes many thousand square miles more.

The formation, after deposition and before burial or erosion, had an extremely wide distribution, which may have amounted to four or five hundred thousand square miles.

Relation to Underlying Rocks

In various areas the Morrison rests on formations of different ages, ranging from Archean to upper Jurassic. In the southwestern areas the Morrison or McElmo rests on the La Plata sandstone of Jurassic age. The contact with the La Plata is apparently conformable, but there is a decided break beneath the La Plata. The latter lies on the Dolores beds of Triassic age, in some localities; on the Cutler, Hermosa and Elbert formations, of Permian,? Pennsylvanian and Devonian ? age respectively (Cross and Larsen, 1914, 7) ; and in still other areas on pre-Cambrian crystallines. In northwestern Utah, near Vernal, the non-marine portion of the Flaming Gorge formation, equivalent to the Morrison, rests on marine beds of upper Jurassic age, containing *Pseudomonotis curta*, etcetera. The contact is apparently conformable, no sudden change in lithological characters being observable.

In the areas of Morrison outcrops in Montana, and in most of those in Wyoming, the formation rests on the Sundance or corresponding beds. These beds have been determined by Stanton (1909, 9) to belong to the lower part of the upper Jurassic. In certain areas in Montana there is evidence of a pre-Sundance erosion plane. The contact between the Morrison and Sundance formations is sharp in some places, while in other places it is obscure.

In general it appears that there was a slight break between the Morrison and Sundance formations, but not one of any considerable extent.

In the Black Hills area the Morrison usually lies on the Sundance beds, often with a sharp contact. In some localities, however, the Morrison is separated from the Sundance by the Unkpapa sandstone, indicating an interval between the retreat of the Sundance sea and the beginning of Morrison deposition.

In eastern Colorado the Morrison rests on Sundance beds near the Wyoming boundary. Throughout most of the area in eastern Colorado and New Mexico the Morrison rests on Red Beds of various ages. In the northern half of Colorado, except at the extreme northern end, the Morrison lies on the Chugwater Red Beds. At Morrison the formation is separated from the Red Beds by a white sandstone of unknown age. At Colorado City a bed of gypsum lies between the Morrison and the Red Beds. Farther south in Colorado the Morrison rests on the Fountain or Badito formations. South of Beulah, in southern Colorado, the Morrison rests directly on the crystallines. In northeastern New Mexico the Morrison is underlain mostly by Red Beds, which have been warped and eroded before the deposition of the Morrison. Near Exeter there is a distinct sandstone formation between the Morrison and the Red Beds. The uppermost members of the Red Bed series often consist of gypsum in this area.

It is seen from the above description that there is a widespread erosion plane beneath the Sundance formation in some areas, and there is evidence of a slight break between the Morrison and Sundance formations. Is the pre-Sundance erosion plane to be correlated with the pre-Morrison plane, which is observable where the Sundance is absent, or is the pre-

Morrison plane to be correlated with the interval between the Morrison and the Sundance? This question will be discussed in the section on the interpretation of the Morrison formation.

RELATION TO OVERLYING BEDS

In western Colorado and eastern Utah the Morrison is overlain by the Dakota sandstone. The contact is fairly sharp, but without definite

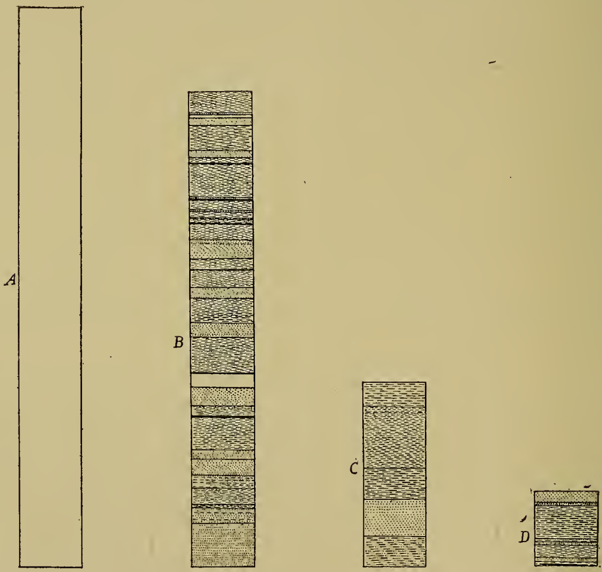

FIG. 78.—*Sections of the Morrison formation showing decrease in thickness from southwestern Colorado northward.*

A. Telluride quadrangle, Colorado; maximum thickness 900 feet; B. Mack, Colorado, thickness about 700 feet; C. Tensleep, Wyoming, thickness about 250 feet; D. Belt Creek, Montana, thickness about 125 feet. Scale, 250 feet to 1 inch.

evidence of erosion of the Morrison prior to the deposition of the Dakota. In Montana the Morrison is overlain by the Kootenie formation. The Kootenie is very similar to the Morrison and may belong to the same deposition cycle. In various areas in central Wyoming, from the Montana south to the Colorado line, the Morrison is overlain by the Cloverly formation, the lower part of which is probably equivalent to the Lakota. In the Black Hills area the Morrison is overlain by the Lakota sandstone.

In eastern Colorado and New Mexico the Purgatoire formation overlies the Morrison. In all three of these last-mentioned areas the contact between the Morrison and the overlying formation is sharp. Near Cañon City, Colorado, marine fossils of Washita age were found by Stanton in beds immediately overlying the Morrison.

In general, the contact between the Morrison and overlying beds is sharp, but there is no evidence of a break of any great extent between

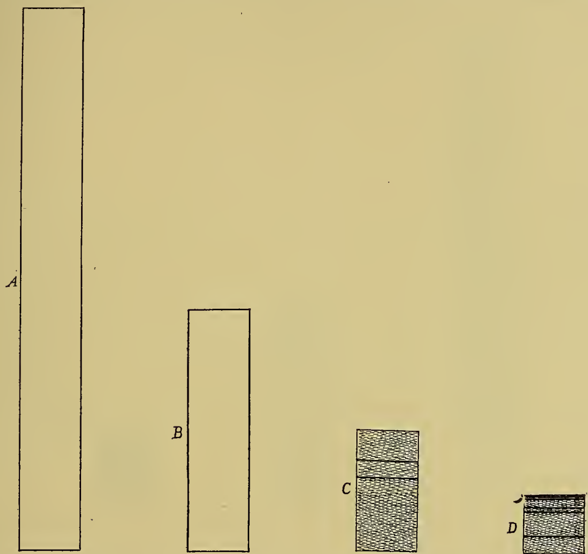

FIG. 79.—*Sections of the Morrison formation showing decrease in thickness from southwestern Colorado northeastward.*

A. Telluride quadrangle, Colorado, maximum thickness 900 feet; B. Encampment District, Wyoming, thickness 400 feet; C. Como Bluff, Wyoming, thickness about 200 feet; D. Devil's Tower, Wyoming, thickness about 100 feet. Scale, 250 feet to 1 inch.

the two formations. As noted by Lee (1915, 2), the Morrison is much more closely related to the overlying formations than to those underlying it.

THICKNESS

In a general way, it will be noticed, on studying the various sections of the Morrison formation, that the thickness is much greater in the western and especially the southwestern areas than in any of the other districts in which the formation occurs. According to Lupton (1914, 3), the McElmo is over 1,000 feet thick near Green River, Utah; in the Telluride quadrangle, according to Cross (1899, 3), it varies from 400 to 900 feet; in McElmo Canyon it is between 400 and 500 feet; in the Grand River Valley, at various points between Grand Junction and the Colorado-Utah line, it is about 700 feet thick; in the region south of the Uinta Mountains the formation is about 650 feet thick; in the region of

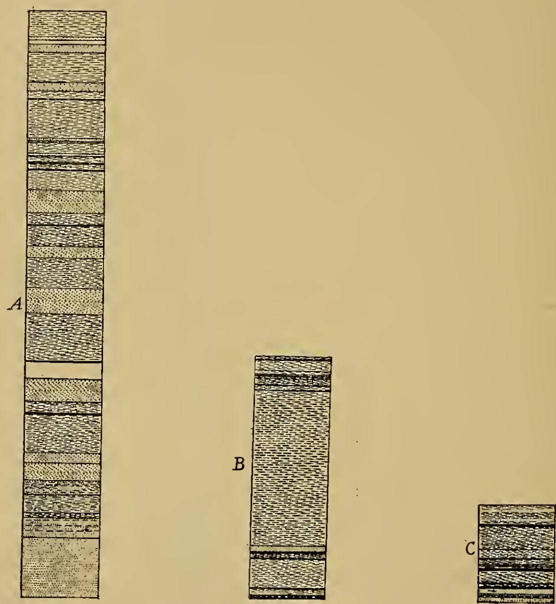

Fig. 80.—*Sections of the Morrison formation showing decrease in thickness from western Colorado eastward.*

A. Mack, Colorado, thickness about 700 feet; B. Cañon City, Colorado, thickness about 325 feet; C. Red Rocks Canyon, Colorado, thickness about 140 feet. Scale, 250 feet to 1 inch.

the Owl Creek and Bighorn Mountains the formation is usually between 200 and 250 feet thick; in the Great Falls region of Montana, about 100 feet thick. It must be remembered in this connection that some of the Kootenie of this area may be Morrison. In the Shoshone River region the formation is 580 feet thick; in the Encampment district, in southern Wyoming, the thickness is about 400 feet; at Como Bluff and in the Freezeout Hills about 200 feet; and in the Black Hills usually less than 100 feet, in one locality disappearing completely. In central Colorado the thickness is about 450 feet; near Cañon City, between 350 and 400 feet; in east-central New Mexico the Morrison varies from 200 to 400 feet; and in the canyons of eastern Colorado the thickness is about 200 feet.

There is thus a thinning out towards the north, northeast and especially towards the east.

LITHOLOGIC CHARACTERS

Coarse material occurs throughout the formation, but is much more abundant and in much thicker beds in the western areas than in those farther east. Fine material occurs throughout the formation and comprises the largest and most typical element in it, but is not usually abundant near the base.

VARIABLE CHARACTER OF SECTIONS

Sections of the Morrison formation, taken in different areas, present both similarities and differences. Most sections contain alternating series of banded or variegated clays or grits and heavy sandstones, with occasional thin limestone beds. No single stratum, however, continues for long distances, so far as the conditions are known. A bed of sandstone a certain number of feet from the base in one section may die out and not be represented in another section, or may disappear and another sandstone take its place. Lee has used the term "uniformly variable" for the Morrison beds, a term which fits Morrison conditions very well.

The significance of these features will be discussed in the section on the interpretation of the formation.

STRUCTURE AND PETROGRAPHY

Structural Features of the Morrison Formation

Several structural features are often met with in the Morrison, which have considerable significance in regard to the question of the origin of the formation. Among these are cross-bedding, of both stream and wind types, lense-shaped cross-section of beds, and distinct channeling.

The stream type of cross-bedding, or cross-bedding in one direction with the inclined beds resting on flat surfaces, is seen throughout the formation in many places. It occurs on a large scale and also on a small scale. Usually the discordance of dips is not very great.

The wind type of cross-bedding, or cross-bedding at various angles and directions, with the inclined beds resting on curved surfaces, is also seen. It has been noticed near Cañon City in the vicinity of the Marsh-Hatcher dinosaur quarry. It has been noted by Dr. H. E. Gregory[5] in the southwestern areas in beds 200 feet or more in thickness.

Channeling is an especially characteristic feature of the Morrison formation. It is widespread and occurs on both large and small scales.

Thinning out of individual beds is common, when erosion channels may not be visible to the eye.

Several of these features are well shown at the dinosaur quarry worked by Professor O. C. Marsh's collectors, and later by Mr. J. B. Hatcher for the Carnegie Museum. The quarry is situated on the north bank of a

FIG. 81.—*Type of cross-bedding usually known as the stream type.*

small gulch which empties into Oil Creek, about eight miles north to northeast of Cañon City, Colorado. The beds for a short distance above and below the level of the quarry are well shown on both sides of the gulch.

The section of the Morrison in the vicinity of the quarry is as follows:

	Feet
Variegated clays	..
White sandstone	5 est.
Bone-bearing sandstone, coarse, calcareous, somewhat arkosic, with grains of volcanic material	3
Strongly cross-bedded sandstone at the floor of the quarry	5
Clay (absent at the quarry but present on the opposite side of the gulch)	1—
Sandstone, white, fairly coarse	2 to 15
Clay with nodule layers	..

[5] Personal communication.

The base of the formation is not shown in this section,[6] but judging from another outcrop in the bank of Oil Creek, a few hundred feet east of the quarry, the base of the quarry-floor sandstone is about 80 feet above the calcareous sandstone which is here considered as immediately underlying the Morrison.

The quarry-floor sandstone is cross-bedded; on the north side of the gulch the cross-bedding is of the stream type, with the beds dipping north; on the south side of the gulch the upper part of the quarry-floor sandstone shows cross-bedding of the wind type.

The heavy sandstone member below the quarry-floor sandstone is semi-lense-shaped in cross-section and occupies a trough in the clays beneath. The trough is a hundred feet or so in breadth and about 13 feet deep, the sandstone which fills and covers it varying from 2 to 5 feet in thickness. The contact between the clays and the sandstone in the trough is very sharp. The only satisfactory explanation of this trough is that the clays

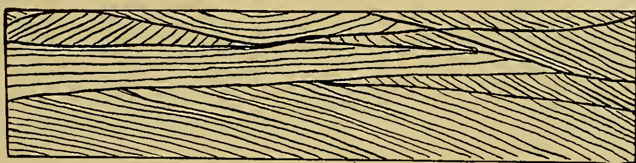

Fig. 82.—*Type of cross-bedding usually known as the æolian type.*

were eroded and the sandstone deposited over them, by a stream of considerable size. This means a stratigraphic break. While the channel in the clays was being eroded and before the deposition of the sands filling it, continuous deposition must have been going on in some other areas. This break need not have been long, in fact was probably short, as the same stream which eroded the channel probably deposited the sands on suffering an increase of load or a decrease of volume or gradient.

The gulch cuts directly across the old channel at this locality, and therefore exposes its characteristics completely. Stream banks cut parallel to old channels would not show their trough character at all, and banks exposed obliquely to old channels in position would exhibit a long gradual thinning out of the beds, without any pronounced lense-shaped cross-section. Thinning out of this character is common throughout the entire area of Morrison outcrops, and distinct lense-shaped sections, which are only exposed under very favorable circumstances, are not rare. Stream channeling and deposition are consequently especially characteristic features of the Morrison formation.

[6] See also figs. 8 and 9, p. 50.

The presence of small stratigraphic breaks at many localities and levels in the Morrison formation emphasizes the force of the statements of Hatcher, that in the production of a continental formation of the character of the Morrison, the main process of deposition is not continuous for any given area. The process is rather one of alternating deposition and erosion, deposition being the dominant factor. The situation is analogous with the conditions at the front of a glacier, where the ice front may stand still, while the actual ice advances, through melting at the front. If melting goes on faster than ice advance, the front retreats;

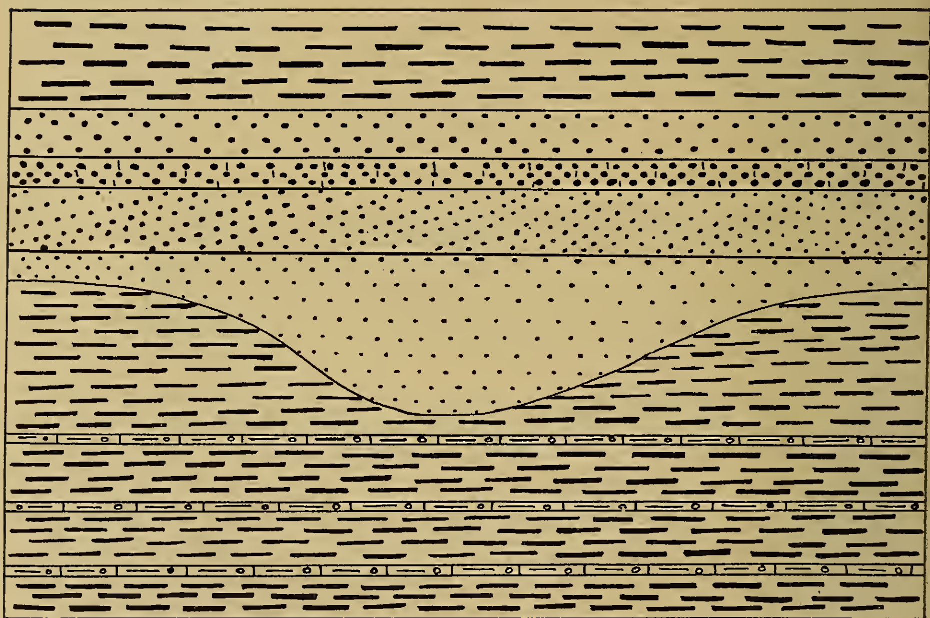

FIG. 83.—*Diagrammatic section of the exposure of the Morrison formation at the Marsh-Hatcher dinosaur quarry, near Cañon City, Colorado.*

if melting goes on slower than ice advance, the front advances. In the case of a continental formation ultimate deposition of a considerable thickness would be brought about by excess of deposition over erosion. If erosion predominated over deposition, there would be no formation produced, but a great stratigraphic break.

In considering the age of such a formation as the one under consideration, it must be remembered that deposition under the conditions indicated above will be much slower in producing a great thickness of beds than under conditions of continuous deposition. A total thickness of

200-400 feet produced by deposition predominating over erosion, means a much greater time interval than the same thickness deposited under conditions of continuous deposition.

Sudden lithologic changes from one bed to another are very common in the Morrison. Fine clay-shales will be overlain by coarse cross-bedded sandstones and the reverse. These abrupt successions do not necessarily mean breaks or lost time intervals, but rather sudden changes of conditions in definite areas.

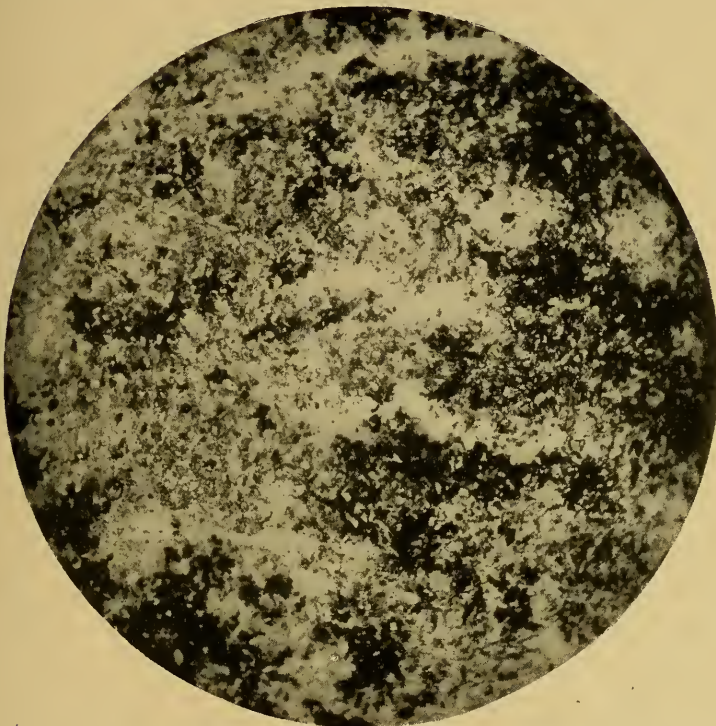

FIG. 84.—*Red hematitic grit, from the top of the Morrison formation at Garden Park, near Cañon City, Colorado.*

The light grains are quartz; the light patches are holes in the slide; the dark areas are clay stained with hematite. About 28 ×.

PETROGRAPHIC CHARACTERS OF THE MORRISON FORMATION

A number of distinct types of sediments occur in the Morrison formation. Broadly speaking, these are: (1) fine red or brown sandstones; (2) clays; (3) calcareous sandstones; (4) limestones; (5) coarse white sandstones. These grade into each other in a rather complex manner, forming many intermediate varieties. Other types are also present, but in minor amounts.

The most characteristic beds in the Morrison are the so-called "joint-clays." These are fine sediments which have the appearance of clay, and which weather into clays. They are variegated in color, and have been the cause of the name "variegated beds" formerly applied to the formation. These "joint-clays" are composed of a variety of sedimentary types,

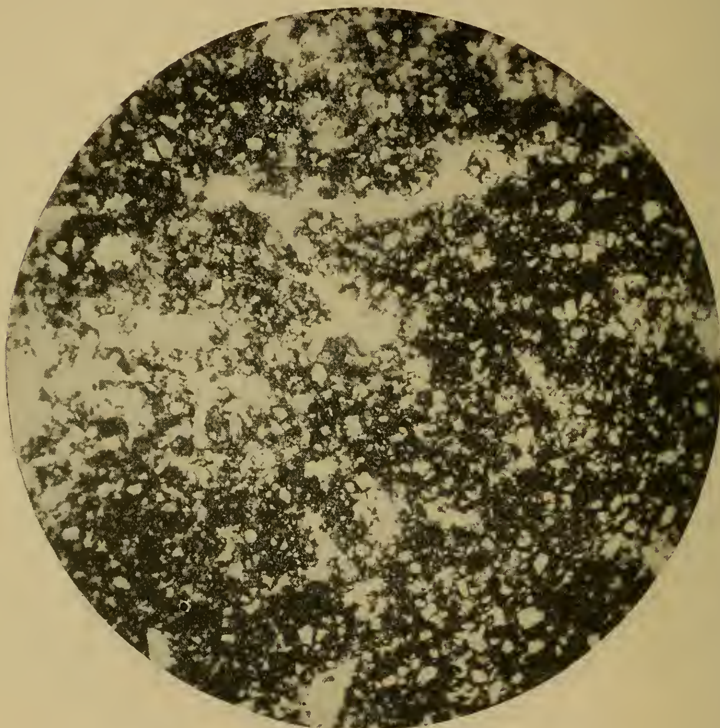

FIG. 85.—*Fine grit, from near the top of the Morrison formation at Garden Park, Colorado.*

The light grains are quartz; the light patches are holes in the slide; the dark patches are limonite. About 28 ×.

more or less distinct from each other in character, though there are often gradational varieties. This variety of elements is responsible for the variegated color. The sediments which make up the "joint-clays" are: fine-grained hematitic sandstones or grits; true kaolinic clays; fine calcareous sandstones; siliceous limestones; and argillaceous limestones. Intermediate or compound types are also abundant.

The first variety of sediment to be considered is the fine hematitic sandstone. As this is composed largely of fine angular quartz grains, it will be spoken of as a grit. This grit is usually more prominent in the upper members of the formation in any given locality, but also occurs in smaller amount near the base. In the field it is reddish to chocolate brown in color. In thin section, seen with reflected light, it is red. The principal mineral constituent is quartz, in small grains. The interstitial

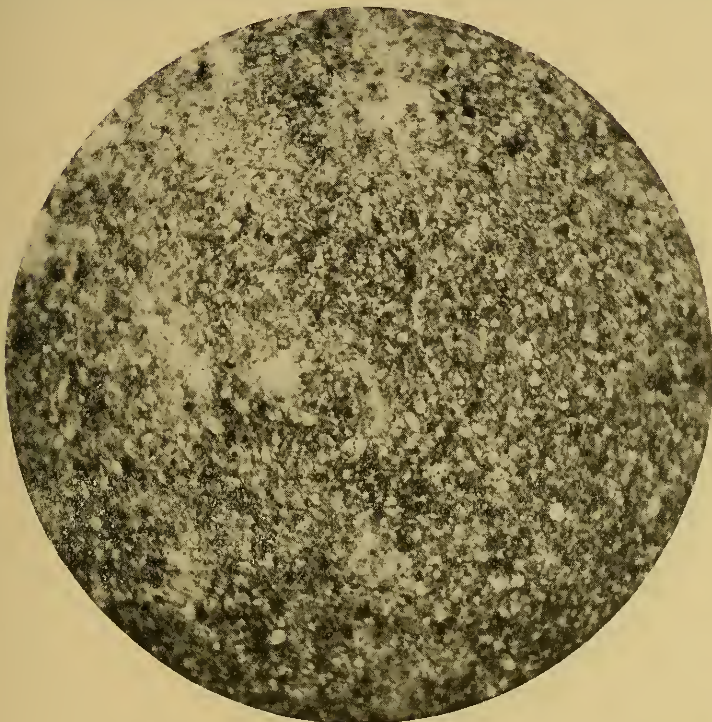

FIG. 86.—*Argillaceous limestone or calcareous clay, from the lower part of the Morrison formation near Mack, Colorado.*

About 28 ×.

material is clayey matter stained to a bright red by hematite. The origin of this hematite will be discussed below. The relative proportions of quartz and hematitic matrix vary greatly.

This red quartz grit grades into fine calcareous sandstone through fine sands with the interstitial matter partly stained by hematite and partly made up of fine-grained carbonates. It also grades into the true clays through members with a similar amount of quartz and a considerable amount of kaolin. Such a type occurs near the top of the Garden Park section (Fig. 85). The iron in this case is sometimes, at least, in the form of limonite, rather than hematite. Magnetite is present in small amounts, and dense patches of limonite represent oxidized pyrite. The kaolin is more or less abundant and is mixed with fine-grained carbonitic material. Hematite is also present in small amount.

The hematite in the red or brown grits has probably originated through oxidization of the siderite present in the light colored calcareous sand-

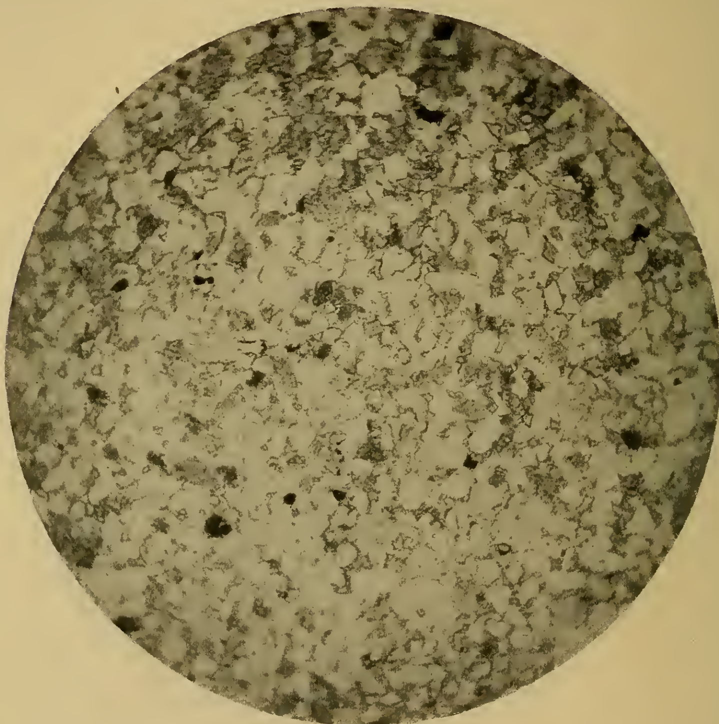

FIG. 87.—*Calcareous sandstone, from the lower beds of the Morrison formation at Garden Park, Colorado.*

The clear grains are quartz, and the mottled grains are calcite. About 28 ×.

stones. The iron carbonate was probably present in the original deposits. The alteration may have taken place to some extent before burial, but it is more likely that it is the result of a long-continued process in the buried rock.[7]

The clays are nearly always impure. They usually contain, along with the kaolin, a considerable amount of fine angular quartz and very

[7] See the discussion of the origin of the formation, p. 168.

fine granular calcite and other carbonates. Mixtures of this kind comprise a large proportion of the formation.

Fine calcareous sandstones are very common and occur in thick beds. They consist typically of fine angular quartz with a matrix of fine granular calcite and probably dolomite and siderite. They grade into the clays through varieties with more kaolinic matter, and into the limestones through members with less quartz. They also grade into arkoses through

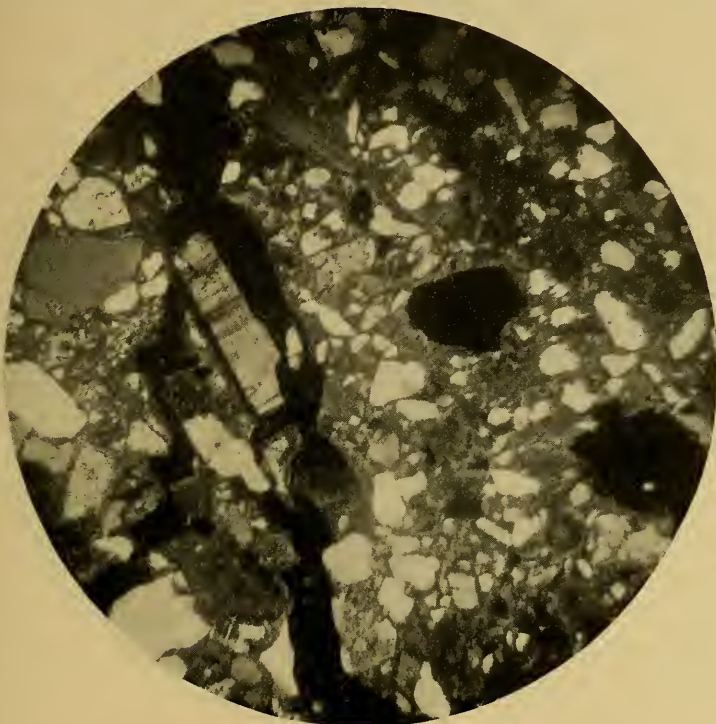

FIG. 88.—*Calcareous arkosic sandstone, from the lower beds of the Morrison formation at Garden Park, Colorado.*

The clear light and dark grains are quartz; the interstitial material is calcite; and the banded grains are plagioclase feldspar. About 28 ×. (Crossed nicols.)

fine sandstones in which feldspars occur. The latter are especially abundant in the lower beds of the formation. The calcareous sandstones also grade into quartz sandstones through varieties with less calcite and more quartz.

The limestones are usually only a foot or two in thickness. They vary from practically pure carbonates to siliceous and argillaceous varieties. Small molluscan fossils are sometimes present.

Calcareous nodules and concretions often form beds amidst less calcareous sandstones or clays.

The coarser sandstones vary from nearly pure quartz sands to highly calcareous and arkosic members. One of the typical coarser sandstones is that in which the dinosaur bones occur in the Marsh-Hatcher quarry near Cañon City, Colorado. This sandstone consists largely of medium-sized to large quartz grains, often well rounded, with finer angular quartz

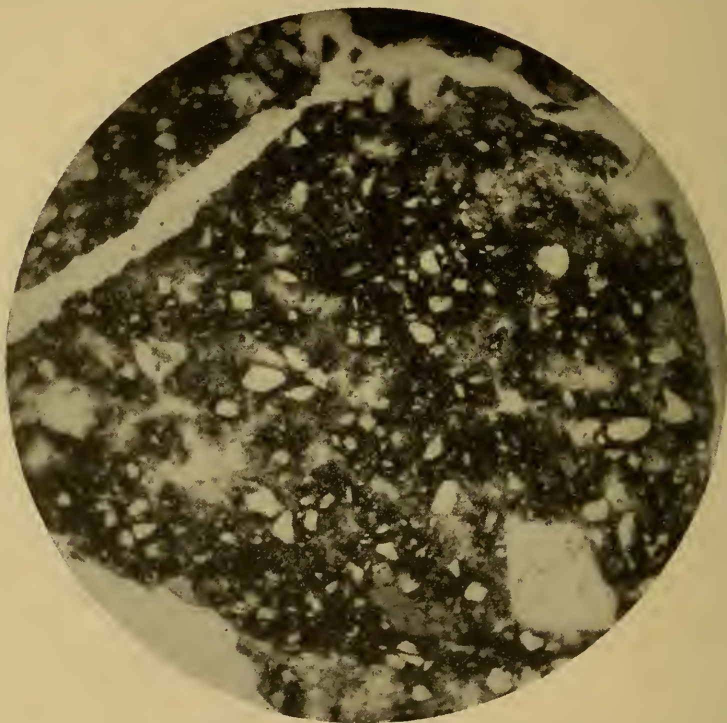

FIG. 89.—*Calcareous argillaceous sandstone, from the Morrison formation near Cañon City, Colorado.*

The light grains are quartz; and the dark interstitial material is mixed carbonates and clay. About 28 ×.

grains scattered among them. Feldspars are fairly abundant and often of large size. Volcanic ash grains occur, some of which are perfectly fresh, others being altered to masses of granular quartz. Calcite, and probably some dolomite, occurs in the interstitial spaces. Some of this is granular and some of it is coarsely crystalline.

Coarse, round-grained sandstones of this type often show æolian cross-bedding.

Hard, quartzitic sandstones, with clay pebbles, often occur.

Conglomerates occur occasionally, but are not especially abundant and are never very coarse.

Gypsum is fairly abundant in the formation, but not in the form of distinct beds.

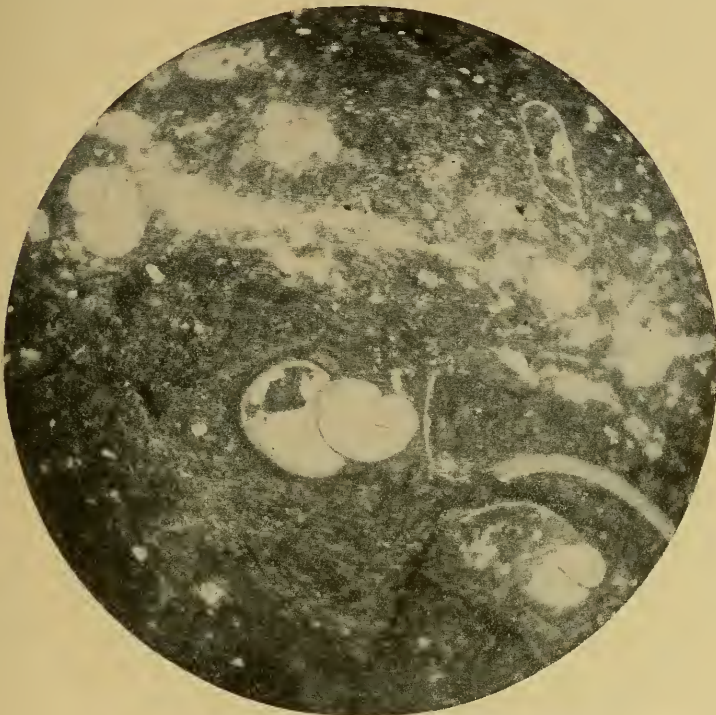

FIG. 90.—*Fossiliferous limestone, from the Morrison formation near Cañon City, Colorado.*

About 28 ×.

The coarse sandstones are often resistant and stand out in cliffs (Fig. 32). In some cases where they are very calcareous, the coarser beds are friable and crumble easily. The finer materials are usually easily eroded, but are sometimes resistant to the hammer.

PALEONTOLOGY

Flora of the Morrison Formation

The following species of cycads from the Morrison formation have been described by Ward:

Cycadella reedii	*Cycadella ferruginea*
Cycadella beecheriana	*Cycadella contracta*
Cycadella wyomingensis	*Cycadella gravis*
Cycadella knowltoniana	*Cycadella verrucosa*
Cycadella compressa	*Cycadella jejuna*
Cycadella jurassica	*Cycadella concinna*
Cycadella nodosa	*Cycadella crepidaria*
Cycadella cirrata	*Cycadella gelida*
Cycadella exogena	*Cycadella carbonensis*
Cycadella ramentosa	*Cycadella knightii*

There is also *Cycadella utopiensis* (Ward) Wieland, *Araucarioxylon ? obscurum* Knowlton, and possibly *Pinoxylon dacotense* Knowlton.[8]

This flora is of no great value in indicating the age of the formation, but it does signify that the climate in which it lived was warm and probably moist in places at least.

Invertebrate Fauna of the Morrison Formation

The invertebrate fauna of the Morrison consists of fresh-water pelecypods and gastropods, with a few crustaceans. A number of species have been described and considerable material collected. There is nothing in the fauna of any value in determining the age of the formation. The following species have been described:

PELECYPODA

Unio felchii White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 16, pl. 1, figs. 1-5, 1886.

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[8] The flora is described and discussed in the following works:

Ward, L. F. Description of a New Genus and Twenty New Species of Fossil Cycadean Trunks from the Jurassic of Wyoming. Wash. Acad. Sci., Proc., vol. i, pp. 253-300, pls. xiv-xxi, 1900.

Ward, L. F. Status of the Mesozoic Floras of the United States. U. S. Geol. Surv., 20th Ann. Rep., pt. 2, pp. 211-747, pls. xxi-clxxix, 1900.

Ward, L. F. Status of the Mesozoic Floras of the United States. U. S. Geol. Surv., Monograph No. 48, pt. 1, text, 616 pp., pt. 2, plates, 119 pls., 1905.

Wieland, G. R. American Fossil Cycads. Carnegie Inst. Wash., Pub. 34, 286 pp., 50 pls., 137 figs., 1906.

Berry, E. W. Lower Cretaceous Floras of the World. Md. Geol. Surv., vol. Low. Cret., pp. 99-151, 1 fig., 1911.

Unio toxonotus White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, figs. 1, 2, 1886.

Unio macropisthus White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, fig. 7, 1886.

Unio iridoides White, On the Fresh-Water Invertebrates of the North

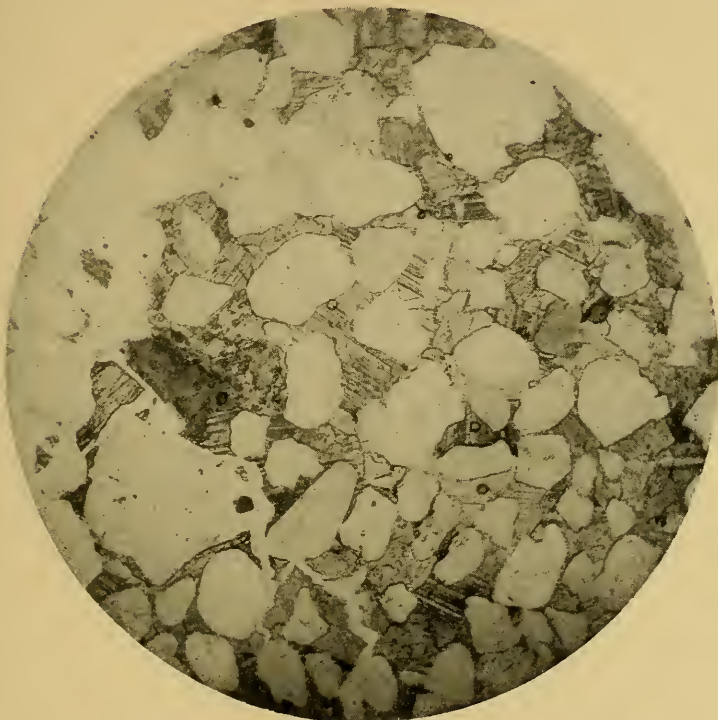


FIG. 91.—*Calcareous arkosic sandstone, from the Morrison formation near Cañon City.* The clear round grains are quartz and feldspar; the interstitial banded grains are calcite; and the large grain at the left, with the dark grain above it, is replaced volcanic ash. About 28 ×.

American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, figs. 3, 4, 1886.

Unio lapilloides White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 18, pl. 2, figs. 5, 6, 1886.

Unio stewardi White, Report on the Geology of the Eastern Portion of the Uinta Mountains and a Region of Country Adjacent Thereto, by J. W.

Powell, p. 110. U. S. Geological and Geographical Survey of the Territories, 1876.

Unio nucalis Meek and Hayden, Phila. Acad. Nat. Sci., Proc. 1858, p. 52.

Unio willistoni Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 133, pl. 31, fig. 10, 1900.

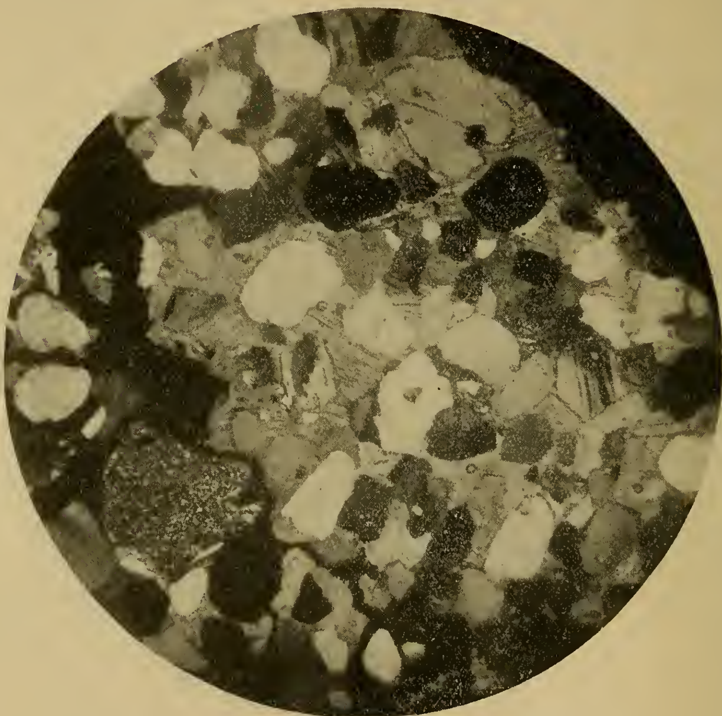


FIG. 92.—*The same slide and field as fig. 91, with crossed nicols.*
This shows the banded feldspars and the granular quartz which has replaced the volcanic ash.

Unio knighti Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 134, pl. 31, figs. 7, 9, 1900.

Unio baileyi Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 134, pl. 31, figs. 4, 6, 8, 11, 1900.

GASTROPODA

Limnœa ativuncula White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 10, 11, 1886.

Limnœa consortis White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 8, 9, 1886.

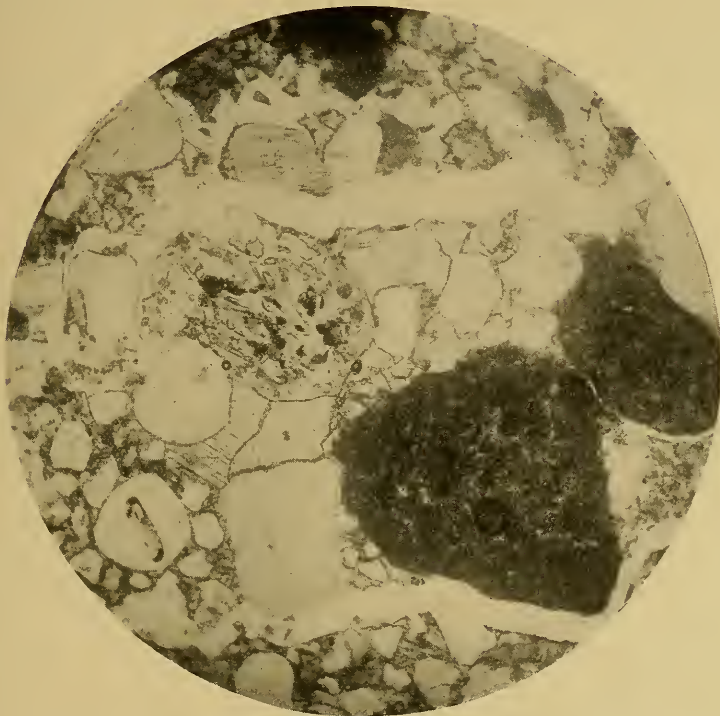


FIG. 93.—*Calcareous arkosic sandstone; the same rock as figs. 91 and 92.* The large dark grains are partly replaced volcanic ash, and the large grain with inclusions in the center of the field is unaltered volcanic ash. About 28 ×.

Limnœa ? accelerata White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 12-15, 1886.

Planorbis veternus Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for 1860, p. 418, 1861.

Vorticifex stearnsii White, On the Fresh-Water Invertebrates of the

North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 21, pl. 4, figs. 4-6, 7, 1886.

Valvata scabrida Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Oct. 1860, p. 418, 1861.

Viviparus gilli Meek and Hayden, Palæontology of the Upper Missouri. Smiths. Contr. Knowledge, vol. xiv, no. 4, p. 115, pl. 5, figs. 3a, 3b, 1865.

Lioplacodes veternus Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Dec. 1861, p. 444 [1862?].

Neritina nebrascensis Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Dec. 1861, p. 444 [1862?].

Valvata leei Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 133, pl. 31, figs. 1-3, 1900.

OSTRACODA

The following ostracods are reported by White, identified by T. Rupert Jones:

Metacypris forbesii Jones.

Metacypris ? Bears a distant resemblance to "*Cypris ? conculcata*" Jones.

Darwinula leguminella E. Forbes.

Cypris purbeckensis ? Forbes sp.

Two undetermined species of *Cypris*.

ARUNDEL FORMS

The following species are reported by W. B. Clark from the Arundel formation of Maryland:

Bythinia arundelensis Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 211, pl. 21, fig. 6, 1911.

Viviparus marylandicus Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 212, pl. 21, figs. 1-3, 1911.

Viviparus arlingtonensis Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 212, pl. 21, figs. 4, 5, 1911.

Cyrena marylandica Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 213, pl. 21, figs. 8, 9, 1911.

The only reference of importance in connection with the invertebrate fauna of the Morrison formation not included in the above list is: White, C. A. Review of the Non-Marine Fossil Mollusca of North America. U. S. Geol. Surv., 3rd Ann. Rep., pp. 405-550, 32 pls., 1883.

The invertebrate fauna is exclusively fresh-water in character.

Vertebrate Fauna of the Morrison Formation

The vertebrate fauna of the Morrison formation is a remarkable one. It consists of a number of primitive mammals, a variety of reptiles, and a few fish. The most conspicuous element in the fauna is the dinosaurs. Representatives of the three principal groups of dinosaurs are present, each with a number of forms. The Sauropoda are especially abundant, being represented by many genera and species. In fact, all the American Sauropoda occur in beds of Morrison age, or very close to it. It is beyond the province of the present paper to enter into an extensive discussion of the various vertebrate remains in detail. The more important forms are discussed briefly. References are given to the original literature on the various forms.

MAMMALIA

Allodon laticeps Marsh

Allodon laticeps Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511, 1881.

Allodon fortis Marsh

Allodon fortis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (331), 1887.

Asthenodon segnis Marsh

Asthenodon segnis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxi, p. 327 (336), 1887.

Dryolestes priscus Marsh

Dryolestes priscus Marsh, Fossil Mammals from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xv, p. 459, 1878.

Dryolestes arcuatus

Dryolestes arcuatus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396 (397), 1879.

Dryolestes gracilis Marsh

Dryolestes gracilis Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511 (513), 1881.

Dryolestes obtusus Marsh

Dryolestes obtusus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (237), 1880.

Dryolestes vorax Marsh

Dryolestes vorax Marsh, Additional Remains of Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 215, 1879.

Ctenacodon serratus Marsh

Ctenacodon serratus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396, 1879.

Ctenacodon nanus Marsh

Ctenacodon nanus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xx, p. 511 (512), 1880.

Ctenacodon potens Marsh

Ctenacodon potens Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (333), 1887.

Dicrocynodon victor Marsh

Diplocynodon victor Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235, 1880.

Dicrocynodon victor Marsh. (In Osborn, H. F. On the Structure and Classification of the Mesozoic *Mammalia*. Phila. Acad. Nat. Sci., Journ. (2), ix, p. 186 (263), 1888.)

Docodon striatus Marsh

Docodon striatus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511 (512), 1881.

Ennacodon crassus Marsh

Enneodon crassus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (339), 1887.

Ennacodon crassus Marsh, Additional Genera established by Prof. O. C. Marsh, 1880-1889. Printed privately, probably in 1889.

Ennacodon affinis Marsh

Enneodon affinis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (339), 1887.

Ennacodon affinis Marsh, Additional Genera Established by Prof. O. C. Marsh, 1880-1889. Printed privately, probably in 1889.

Paurodon valens Marsh

Paurodon valens Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (342), 1887.

Stylacodon gracilis Marsh

Stylacodon gracilis Marsh, Notice of a New Jurassic Mammal. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 60, 1879.

Stylacodon validus Marsh

Stylacodon validus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (236), 1880.

Laodon venustus Marsh

Laodon venustus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (337), 1887.

Priacodon ferox Marsh

Tinodon ferox Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (236), 1880.

Tricondon ferox Cope, The Mechanical Causes of the Development of the Hard Parts of the Mammalia. Journ. Morph., vol. iii, p. 137 (227), 1889.

Priacodon ferox Roger, Verzeichniss der bisher bekannten fossilen Säugethiere. Neu zusammengestellt von Dr. Otto Roger, kgl. Regierungs-und-Kreis-Medizinrath in Augsburg. Bericht. naturwiss. Vereins f. Schwaben und Neuberg (a. V.), xxxii, p. 1, 1896.

Menacodon rarus Marsh

Menacodon rarus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (340), 1887.

Tinodon bellus Marsh

Tinodon bellus Marsh, Additional Remains of Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 215 (216), 1887.

Tinodon lepidus Marsh

Tinodon lepidus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396 (398), 1879.

Tinodon robustus Marsh

Tinodon robustus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396 (397), 1879.

Triconodon bisulcus Marsh

Triconodon bisulcus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (237), 1880.

The mammals are all archaic in character and belong to primitive forms of marsupials and monotremes. They are known only from jaws and teeth.

Valuable information concerning the Morrison mammals is contained in "American Jurassic Mammals," by O. C. Marsh; "On the Structure and Classification of the Mesozoic *Mammalia*," by H. F. Osborn; and "Evolution of the Mammalian Molar Teeth," by H. F. Osborn. For further references the reader is referred to O. P. Hay's "Bibliography and Catalogue of the Fossil Vertebrata of North America."

AVES

Laopteryx priscus Marsh

Laopteryx priscus Marsh, Discovery of a Fossil Bird in the Jurassic of Wyoming. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 341, 1881.

From the Morrison formation of Wyoming, probably from Como Bluff. Known from part of a skull.

REPTILIA

DINOSAURIA

SAUROPODA [9]

Astrodon johnstoni Leidy

Astrodon Johnston, Amer. Journ. Dental Sci., 1859.

Astrodon johnstoni Leidy, Memoir on the Extinct Reptiles of the Cretaceous Formations of the United States. Smiths. Contr. Knowledge, xiv, pp. 102, 119, 1865.

This form is known from teeth only. It was discovered in the Arundel beds of Maryland.

[9] This group will be treated thoroughly in the forthcoming monograph by Professor H. F. Osborn.

Dystrophæus viæmalæ Cope

Dystrophœus viœmalœ Cope, On a Dinosaurian from the Trias of Utah. Amer. Philos. Soc., Proc., vol. xvi, p. 579, 1877.

The type locality of this species is Painted Canyon, in southeastern Utah. The beds were considered by Cope to be Triassic, but have since been found to be the McElmo formation. Only a small part of the skeleton is known.

Atlantosaurus montanus Marsh

Titanosaurus montanus Marsh, Notice of a new and Gigantic Dinosaur. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 87, 1877.

Atlantosaurus montanus Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

This form was discovered at Morrison, Colorado. It was the first form of the Sauropoda found in the eastern Rocky Mountain area of the Morrison formation and the one which gave its name to the formation as "Atlantosaurus beds."

Camarasaurus supremus Cope

Camarasaurus supremus Cope, On a Gigantic Saurian from the Dakota Epoch of Colorado. Paleontological Bulletin No. 25, 1877.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. A well known and characteristic Morrison form.

Caulodon diversidens Cope

Caulodon diversidens Cope, On Reptilian Remains from the Dakota Beds of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193, 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known only from teeth.

Apatosaurus ajax Marsh

Apatosaurus ajax Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

Type locality, Morrison, Colorado. Characteristic portions of the skeleton known.

Morosaurus grandis Marsh

Apatosaurus grandis Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

Morosaurus grandis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

This form is widespread in the Morrison formation. The type locality and level is the Morrison formation at Como Bluff, Wyoming. Almost the entire skeleton is known.

Amphicœlias altus Cope

Amphicœlias altus Cope, On Amphicœlias, a genus of Saurians from the Dakota epoch of Colorado. Paleontological Bulletin No. 27 (Amer. Philos. Soc., Proc., vol. xvii, p. 243), 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from a small part of the skeleton.

Amphicœlias latus Cope

Amphicœlias latus Cope, On Amphicœlias, a genus of Saurians from the Dakota epoch of Colorado. Paleontological Bulletin No. 27 (Amer. Philos. Soc., Proc., vol. xvii, p. 243), 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Only a small part of skeleton known.

Symphyrophus musculosus Cope

Symphyrophus musculosus Cope, On the Vertebrata of the Dakota Epoch of Colorado. Paleontological Bulletin No. 28 (Amer. Philos. Soc., Proc., vol. xvii, p. 246), 1878.

From near Cañon City, Colorado, probably from the uppermost beds of the Morrison formation. Not very well known.

Caulodon leptoganus Cope

Caulodon leptoganus Cope, On the Vertebrata of the Dakota Epoch of Colorado. Paleontological Bulletin No. 28 (Amer. Philos. Soc., Proc., vol. xvii, p. 247), 1878.

Same locality and horizon as above. Known only from teeth.

Atlantosaurus immanis Marsh

Atlantosaurus immanis Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241, 1878.

From the middle Morrison beds near Morrison, Colorado. Comparatively small part of skeleton known.

Morosaurus impar Marsh

Morosaurus impar Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 242, 1878.

Type locality and level, Morrison formation at Como Bluff, Wyoming. Known from very imperfect material only.

Epanterias amplexus Cope

Epanterias amplexus Cope, A New Opisthocœlous Dinosaur. Amer. Nat., vol. xii, p. 406, 1878.

Probably from the uppermost Morrison beds near Cañon City, Colorado. Known from very imperfect remains.

Amphicœlias fragillimus Cope

Amphicœlias fragillimus Cope, A New Species of Amphicœlias. Amer. Nat., vol. xii, p. 563, 1878.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Not well known.

Morosaurus robustus Marsh

Morosaurus robustus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

Type locality and level probably the Morrison formation at Como Bluff, Wyoming. Parts of skull and skeleton known.

Diplodocus longus Marsh

Diplodocus longus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

From the middle beds of the Morrison formation near Cañon City, Colorado. Several more or less complete skeletons of this form are known.

Apatosaurus laticollis Marsh

Apatosaurus laticollis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. II. Amer. Journ. Sci., 3rd ser., vol. xvii, p. 88, 1879.

Only a small portion of the skeleton is preserved.

Camarasaurus leptodirus Cope

Camarasaurus leptodirus Cope, New Jurassic Dinosauria. Amer. Nat., vol. xiii, p. 402, 1879.

From the upper beds of the Morrison formation near Cañon City, Colorado. Only a few vertebræ are known.

Brontosaurus excelsus Marsh

Brontosaurus excelsus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 503, 1879.

This form is perhaps the best known of the Sauropoda. The type specimen was found in the Morrison beds at Como Bluff, near Medicine Bow, Wyoming. Other material of the species has been found in the Morrison beds at various localities. Nearly the complete skeleton is known.

Brontosaurus amplus Marsh

Brontosaurus amplus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. V. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 421, 1881.

Morrison formation at Como Bluff. Part of skeleton known.

Diplodocus lacustris Marsh

Diplodocus lacustris Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VII. Diplodocidæ, a New Family of the Sauropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 166, 1884.

Morrison formation near Morrison, Colorado. Known from fragmentary material only.

Pleurocœlus nanus Marsh

Pleurocœlus nanus Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 90, 1888.

From the Arundel beds in Maryland, probably near Muirkirk. Characteristic parts of the skeleton are known.

Pleurocœlus altus Marsh

Pleurocœlus altus Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 92, 1888.

From the Arundel formation near Muirkirk, Maryland. Part of hind limb only is known.

Morosaurus lentus Marsh

Morosaurus lentus Marsh, Notice of New American Dinosauria. Amer. Journ. Sci., 3rd ser., vol. xxxvii, p. 333, 1889.

Morrison beds of Wyoming, probably from Como Bluff. The type specimen consists of a nearly complete skeleton of an immature individual.

Morosaurus agilis Marsh

Morosaurus agilis Marsh, Notice of New American Dinosauria. Amer. Journ. Sci., 3rd ser., vol. xxxvii, p. 334, 1889.

From the middle beds of the Morrison formation near Cañon City, Colorado. The skull and a few other parts of the skeleton are known.

Barosaurus lentus Marsh

Barosaurus lentus Marsh, Description of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxxix, p. 85, 1890.

From the Morrison formation near Piedmont, South Dakota. A comparatively small part of the skeleton is known.

Pleurocœlus montanus Marsh

Pleurocœlus montanus Marsh, The Dinosaurs of North America. U. S. Geol. Surv., 16th Ann. Rep., Pt. 2, p. 184, 1896.

Type locality and horizon unknown. Very little of skeleton is known.

Barosaurus affinis Marsh

Barosaurus affinis Marsh, Footprints of Jurassic Dinosaurs. Amer. Journ. Sci., 4th ser., vol. vii, p. 228, 1899.

From the Morrison formation near Piedmont, South Dakota. Very little of the skeleton is known.

Diplodocus carnegii Hatcher

Diplodocus carnegii Hatcher, Diplodocus Marsh, its Osteology, Taxonomy, and Probable Habits, with a Restoration of the Skeleton. Carn. Mus. Mem., vol. i, p. 1, 1901.

From the Morrison beds near Sheep Creek, Wyoming. Most of the skeleton is well known. Restorations of this form have been installed in many of the large museums of the world; consequently this is one of the best known of the Sauropoda.

Elosaurus parvus Peterson and Gilmore

Elosaurus parvus Peterson and Gilmore, Elosaurus parvus; a new Genus and Species of the Sauropoda. Carn. Mus. Ann., vol. i, p. 490, 1902.

From the Morrison formation near Sheep Creek, Wyoming. Characteristic parts of the skeleton of a young individual are known.

Haplocanthosaurus priscus Hatcher

Haplocanthus priscus Hatcher, A New Sauropod Dinosaur from the Jurassic of Colorado. Biol. Soc. Wash., Proc., vol. xvi, p. 1, 1903.

Haplocanthosaurus priscus Hatcher, A New Name for the Dinosaur Haplocanthus. Biol. Soc. Wash., Proc., vol. xvi, p. 100, 1903.

From the middle beds of the Morrison formation near Cañon City, Colorado. A considerable part of the skeleton is known. The form is the most primitive of the American Sauropoda (along with *H. utterbacki*).

Brachiosaurus altithorax Riggs

Brachiosaurus altithorax Riggs, *Brachiosaurus altithorax,* the Largest Known Dinosaur. Amer. Journ. Sci., 4th ser., vol. xv, p. 299, 1903.

From the McElmo beds in the Grand River Valley, near Fruita, Colorado. This is a remarkable form in which the humerus is longer than the femur. It is represented by several species in German East Africa. The present species is known from characteristic parts of the skeleton.

Haplocanthosaurus utterbacki Hatcher

Haplocanthosaurus utterbacki Hatcher, Osteology of Haplocanthosaurus, with Description of a New Species, and Remarks on the Probable Habits of the Sauropoda and the Age and Origin of the Atlantosaurus beds. Carn. Mus. Mem., vol. ii, p. 27, 1903.

From the middle beds of the Morrison formation near Cañon City, Colorado. It is larger than *H. priscus,* and is known from characteristic parts of the skeleton.

Apatosaurus louisæ Holland

Apatosaurus louisæ Holland, A New Species of Apatosaurus. Carn. Mus. Ann., vol. x, p. 143, 1915.

A large and well characterized form from the Morrison formation near Jensen, Utah.

THEROPODA

Dryptosaurus trihedrodon (Cope)

Lœlaps trihedrodon Cope, U. S. Geol. and Geog. Surv. Terr., vol. iii, art. xxxiii, p. 805, 1877.

Dryptosaurus trihedrodon Marsh, Notice of a new and Gigantic Dinosaur. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 87, 1877. [Footnote to p. 88 states *Lælaps* Cope to be preoccupied by *Lælaps* Koch. *Dryptosaurus* is proposed to replace it.]

Discovered near Cañon City, Colorado. Probably from the uppermost beds of the Morrison formation. Known from fragmentary remains only.

Hypsirophus discurus Cope

Hypsirophus discurus Cope, A New Genus of Dinosauria from Colorado. Amer. Nat., vol. xii, p. 188, 1878.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from part of the skeleton.

Allosaurus fragilis Marsh

Allosaurus fragilis Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514 (515), 1877.

"Upper Jurassic of Colorado." Probably the middle beds of the Morrison formation near Cañon City, Colorado. Known from practically complete skeletons.

Creosaurus atrox Marsh

Creosaurus atrox Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (243), 1878.

From the "Upper Jurassic of the Rocky Mountains," probably the middle beds of the Morrison formation near Cañon City, or near Morrison, Colorado. Known from representative portions of the skeleton.

Antrodesmus lucaris (Marsh)

Allosaurus lucaris Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (242), 1878.

Labrosaurus lucaris Marsh, Principal Characters of American Jurassic Dinosaurs. Amer. Journ. Sci., 3rd ser., vol. xvii, p. 86 (91), 1879.

Antrodesmus lucaris Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (489), 1902.

From the "Upper Jurassic of the Rocky Mountains," probably from the middle beds of the Morrison formation near Cañon City, or near Morrison, Colorado. Small part of the skeleton is known.

Antrodesmus valens Leidy

[Poicilopleuron] (Antrodesmus) Leidy, Phila. Acad. Nat. Sci., Proc., vol. for 1870, p. 3 (4), 1870.

Labrosaurus ferox Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (333), 1884.

Antrodesmus valens Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (490), 1902.

From Middle Park, Colorado. Small part of skeleton known.

Cœlurus agilis Marsh

Cœlurus agilis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (335), 1884.

"Jurassic, Colorado." Probably the middle part of the Morrison formation, near Cañon City, or near Morrison, Colorado. Small part of skeleton known.

Cœlurus fragilis Marsh

Cœlurus fragilis Marsh, Notice of new Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (504), 1879.

"Jurassic." Probably from the Morrison formation. Small part of skeleton known.

This species was about the size of a wolf, being unusually small for a dinosaur.

Tichosteus lucasanus Cope

Tichosteus lucasanus Cope, On Reptilian Remains from the Dakota of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193 (195), 1877.

From near Cañon City, Colorado. Probably from the uppermost beds of the Morrison formation. Only small part of the skeleton is known.

Tichosteus æquifacies Cope

Tichosteus æquifacies Cope, Descriptions of new Extinct Vertebrata from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., vol. iv, p. 379 (392), 1878.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Only a small part of the skeleton is known.

Ceratosaurus nasicornis Marsh

Ceratosaurus nasicornis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (330), 1884.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Most of the skeleton is known.

Ornitholestes hermanni Osborn

Ornitholestes hermanni Osborn, Ornitholestes Hermanni, a New Compsognathoid Dinosaur from the Upper Jurassic. Amer. Mus. Nat. Hist., Bull., vol. xix, art. xii, p. 459, 1903.

From "Bone Cabin Quarry" near Medicine Bow, Wyoming, in the Morrison formation. This form is especially light and small.

Allosaurus medius Marsh

Allosaurus medius Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 89 (93), 1888.

From the Arundel formation, near Muirkirk, Prince Georges County, Maryland. Known from teeth only.

Creosaurus potens Lull

Creosaurus potens Lull, [Systematic Paleontology], Reptilia. Md. Geol. Surv., vol. Low. Cret., p. 183, 1911.

From the Arundel formation in Washington, D. C. Known from fragmentary material only.

Cœlurus gracilis Marsh

Cœlurus gracilis Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 89 (94), 1888.

From the Arundel formation, near Muirkirk, Maryland. Small part of the skeleton is known.

PREDENTATA

Stegosaurus armatus Marsh

Stegosaurus armatus Marsh, A New Order of Extinct Reptilia (Stegosauria) from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 513, 1877.

According to Marsh, the type was found in the Jurassic of the Rocky Mountains in Colorado, near the locality of *Atlantosaurus montanus*. This means the Morrison formation at Morrison. Most of the skeleton is known.

Stegosaurus discurus (Cope)

Hypsirophus discurus Cope, A New Genus of Dinosauria from Colorado. Amer. Nat., vol. xii, p. 188, 1878.

Stegosaurus discurus Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (496), 1902.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Characteristic portions of the skeleton are known.

Stegosaurus seeleyanus (Cope)

Hypsirophus seeleyanus Cope, New Jurassic Dinosauria. Amer. Nat., vol. xiii, p. 402 (404), 1879.

Stegosaurus seelayanus Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (496), 1902.

Locality not given. Hay notes it as from the "Jurassic, Colorado." Characteristic portions of the skeleton are known.

Stegosaurus ungulatus Marsh

Stegosaurus ungulatus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (504), 1879.

Locality not given in the original description, but the form is known to exist in the Morrison formation. The complete skeleton is known. This is one of the best known members of the Morrison fauna.

Stegosaurus affinis Marsh

Stegosaurus affinis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IV. Spinal Cord, Pelvis, and Limbs of *Stegosaurus*. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 167 (169), 1881.

Locality not given. Parts of the skeleton are known.

Stegosaurus stenops Marsh

Stegosaurus stenops Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of Stegosaurus. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (414), 1887.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Practically the complete skeleton is known.

Stegosaurus sulcatus Marsh

Stegosaurus sulcatus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of Stegosaurus. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (415), 1887.

No locality is given. Part of the skeleton is known.

Stegosaurus duplex Marsh

Stegosaurus duplex Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of Stegosaurus. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (416), 1887.

Locality not given. Posterior portion of the skeleton known.

Diracodon laticeps Marsh

Diracodon laticeps Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. V. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 417 (421), 1881.

From the Atlantosaurus beds of Wyoming, probably from Como Bluff. Very little of the skeleton is known.

Stegosaurus longispinus Gilmore

Stegosaurus longispinus Gilmore, Osteology of the Armored Dinosauria in the United States National Museum, with Special Reference to the Genus Stegosaurus. U. S. Nat. Mus., Bull. No. 89, 136 pp., 37 pls., 73 figs., 1914.

From the Morrison 1½ miles east of Alcova, Natrona County, Wyoming. Characteristic portions of the skeleton are known.

Hoplitosaurus marshi Lucas

Hoplitosaurus marshi, from the Lakota beds of the Black Hills region, may also occur in the Morrison formation, but has not been definitely reported.

Camptosaurus dispar Marsh

Camptonotus dispar Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501, 1879.

Camptosaurus [*dispar*] Marsh, Names of Extinct Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxix, p. 169, 1885.

No locality given. Characteristic portions of the skeleton are known.

Camptosaurus amplus Marsh

Camptonotus amplus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (503), 1879.

Camptosaurus [*amplus*] Marsh, Names of Extinct Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxix, p. 169, 1885.

From a lower horizon than *C. dispar.* No locality given. A small part of the skeleton is known.

Camptosaurus medius Marsh

Camptosaurus medius Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85, 1894.

No locality given. Parts of the skeleton are known.

Camptosaurus nanus Marsh

Camptosaurus nanus Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85, 1894.

No locality given. Small part of the skeleton is known. This form is one of the smallest of the dinosaurs, being only about six feet long, according to Marsh's estimate.

Laosaurus celer Marsh

Laosaurus celer Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (244), 1878.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Characteristic portions of the skeleton are known. This form is remarkably bird-like, and is very small, being only about the size of a fox.

Laosaurus gracilis Marsh

Laosaurus gracilis Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (244), 1878.

Locality not given. It is known from Como Bluff. Exceedingly small.

Laosaurus consors Marsh

Laosaurus consors Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85 (87), 1894.

From the Morrison of Wyoming, probably from Como Bluff. Characteristic portions of the skeleton are known.

Dryosaurus altus Marsh

Laosaurus altus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 411 (415), 1878.

Dryosaurus altus Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85 (86), 1894.

From the Morrison formation in Colorado and Wyoming. Characteristic portions of the skeleton are known.

Macelognathus vagans Marsh

Macelognathus vagans Marsh, A New Order of Extinct Jurassic Reptiles (Macelognatha). Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 341, 1884.

Morrison beds of Wyoming, probably from Como Bluff. Known from fragmentary remains only. The position of this form is unknown. Marsh placed it among the turtles and Hay provisionally placed it among the dinosaurs.

Apatodon mirus Marsh

Apatodon mirus Marsh, Notice of Some New Vertebrate Fossils. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 249 (255), 1877.

Lower Cretaceous or Jurassic, according to Marsh, no locality being given. Fragmentary remains only are known. The form is probably a dinosaur.

Camptosaurus depressus Gilmore

Camptosaurus depressus Gilmore, Osteology of the Jurassic Reptile Camptosaurus, with a Revision of the Species of the Genus, and Descriptions of Two New Species. U. S. Nat. Mus., Proc., vol. xxxvi, p. 197 (292), 1909.

The type specimen of this species was discovered in the Lakota beds near Buffalo Gap, South Dakota. A specimen has been found in the Morrison formation near Como, Wyoming, which probably belongs to this species. Known from the posterior portion of the skeleton.

Camptosaurus browni Gilmore

Camptosaurus browni Gilmore, Osteology of the Jurassic Reptile Camptosaurus, with a Revision of the Species of the Genus, and Descriptions of Two New Species. U. S. Nat. Mus., Proc., vol. xxxvi, p. 197 (295), 1909.

From the Morrison formation 8 miles east of Como, Wyoming. Known from a considerable portion of the skeleton.

Brachyrophus altarkansanus Cope

Brachyrophus altarkansanus Cope, Descriptions of New Extinct Vertebrates from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., Bull. No. iv, p. 379 (390), 1878.

Near Cañon City, Colorado, probably from the uppermost beds of the Morrison formation. Known from several vertebræ.

RHYNCHOCEPHALIA

Opisthias rarus Gilmore

Opisthias rarus Gilmore, A New Rhynchocephalian Reptile from the Jurassic of Wyoming, with Notes on the Fauna of "Quarry 9." U. S. Nat. Mus., Proc., vol. xxxvii, p. 35. 1909.

From the Morrison formation at Como Bluff, Wyoming. Known from dentary bones of several individuals.

CROCODILIA

Goniopholis lucasii (Cope)

Amphicotylus lucasii Cope, Descriptions of New Extinct Vertebrata from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., Bull. No. iv, p. 379 (391), 1878.

Goniopholis lucasii Zittel, Handbuch der Palæontologie. I. Abth. Palæozoologie. III Bd., p. 677, 1890.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from vertebræ and skull.

Goniopholis felix (Marsh)

Diplosaurus felix Marsh, Notice of Some New Vertebrate Reptiles. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 249 (254), 1877.

Goniopholis felix Zittel, Handbuch der Palæontologie. I. Abth. Palæozoologie, III Bd., p. 677, 1890.

According to Marsh, from the Lower Cretaceous or Wealden of Colorado. Probably from the middle beds of the Morrison formation near Cañon City, Colorado. This form is known from the skull and a few vertebræ.

Goniopholis gilmorei Holland

Goniopholis gilmorei Holland, A New Crocodile from the Jurassic of Wyoming. Carn. Mus. Ann., vol. iii, p. 431, 1905.

From the Morrison formation in the Freezeout Hills of Wyoming. The skull is known.

CHELONIA

Compsemys plicatulus Cope

(*Syn. Glyptops ornatus* Marsh)

Compsemys plicatulus Cope, On Reptilian Remains from the Dakota Beds of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193 (196), 1877.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from a considerable portion of the skeleton.

PTEROSAURIA

Dermodactylus montanus Marsh

Pterodactylus montanus Marsh, New Pterodactyl from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 233, 1878.

Dermodactylus montanus Marsh, Note on American Pterodactyls. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 342, 1881.

From the Morrison formation in Wyoming, probably from Como Bluff. Known from various remains of wings, teeth, and vertebræ.

PISCES

Ceratodus guntheri Marsh

Ceratodus guntheri Marsh, New Species of Ceratodus, from the Jurassic. Amer. Journ. Sci., 3rd ser., vol. xv, p. 76, 1878.

"Jurassic of Colorado." Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Known from a left lower dental plate.

Ceratodus robustus Knight

Ceratodus robustus Knight, Some New Jurassic Vertebrates from Wyoming. Amer. Journ. Sci., 4th ser., vol. v, p. 186, 1898.

From the Morrison formation in Albany County, Wyoming, associated with crocodile and dinosaur bones. Known from part of a tooth.

Ceratodus americanus Knight

Ceratodus americanus Knight, Some New Jurassic Vertebrates from Wyoming. Amer. Journ. Sci., 4th ser., vol. v, p. 186, 1898.

From the Morrison formation in Carbon County, Wyoming, associated with bones of a carnivorous dinosaur. Known from part of a left mandibular tooth.

This fauna in its general character seems to require low, or at least level and aquatic, conditions. Woodworth (1894, 1), in discussing the relations of peneplanation to organic evolution, states that the reptiles and in particular the dinosaurs are correlated in development with the growth of the peneplain. He makes the following remarks regarding the reptilia:

"Reptilia are characteristic lowland forms. They will endure the cold of high altitudes and latitudes only by falling into a state of torpidity. In the development of the peneplain from the high relief of the Permian, and again, at the close of the Jura-Trias, the widening out of the lowland, with plains and jungles near tide-level, followed by depression of the land, must have highly favored the water-loving reptilia. It is to these geographic circumstances, I think, that we must look for an explanation of the remarkable history of this class in Mesozoic times."

Many of the forms listed above are no doubt synonyms, but their determination is beyond the scope of the present paper.

AGE OF THE MORRISON FORMATION

The age of the Morrison formation has been the subject of considerable discussion in the past. The reports of the early surveys refer to the Morrison beds as "Jurassic beds," "Lower Dakota" and other terms signifying various ages. Cope (1877, 5; 1878, 8) described typical Morrison reptiles as coming from beds of the "Dakota Epoch" in Colorado.

Cope (1884, 1) made a faunal comparison of the Morrison and Wealden formations, but made no definite statement as to their age or correlation. Osborn (1888, 2) compared the mammals of the Morrison with those of the Purbeck beds, and considered the former to be of Jurassic age. Emmons, Cross and Eldridge (1896, 1) stated that from the point of view of the stratigrapher the assignment of the Morrison beds to the Lower Cretaceous (Comanchean) was more desirable than assignment to the Upper Jurassic, "not only because it accords better with the sequence of sedimentation thus far disclosed in the adjoining regions of Kansas and Texas, but because it places the physical break whose effects are recognized over the whole continent between these two great time divisions rather than in the midst of one of them." Marsh (1896, 5; 1896, 7) vigorously maintained the Jurassic age of the Atlantosaurus Beds and correlated them with the Wealden of Europe. Scott (1897, 5) in his Manual of Geology placed the Morrison or Como in the Comanchean. Ward (1900, 6) considered the evidence from the cycads sufficient to place the formation in the Jurassic. Knight (1900, 2) placed the formation in the upper Jurassic, being closer to the Purbeckian than to the Oxfordian in age. Logan (1900, 5) correlated the Morrison of the Freezeout Hills region with the Wealden of England. Riggs (1901, 4) described the Morrison or McElmo of the Grand River Valley as Jurassic. Loomis (1901, 6) noted the resemblance of the Morrison mammalian fauna to the fauna of the Purbeck beds of England, and on this ground assigned the formation to the Jurassic. Hatcher (1903, 4) correlated the lower beds of the Morrison at Cañon City with the Sundance beds in Wyoming. He considered the cycads as pointing to the Jurassic age of the deposits, and the dinosaurs as agreeing most closely with those of the Middle Oölite series of Europe. He concluded that there is undoubtedly Jurassic represented in the formation, but that it was quite probable that some of the formation might be of Lower Cretaceous age. Williston (1905, 4) gave strong evidence from the vertebrate fauna for Comanchean age of the Morrison. Lull (1911, 8) discussed the fauna of the Arundel formation and considered it to be Lower Cretaceous or Comanchean in age.

In view of the great differences of opinion concerning the age of the Morrison it is important to review the evidence at present available on this subject. The principal evidence from the stratigraphic relations is here summarized.

The youngest beds upon which the Morrison rests are the sandstones of the Unkpapa formation in the Black Hills area. (It is possible that the Exeter sandstone in New Mexico may be equivalent in age to the Unkpapa.) Below the Unkpapa, which is thin, lies the Sundance formation. Over wide areas the Morrison lies on the Sundance directly. The Sundance, according to Stanton (1909, 9), belongs to the lower part of the upper Jurassic. The Jurassic sea retreated, therefore, considerably before the close of the Jurassic period, although it is possible that post-Sundance beds were laid down and eroded before the deposition of the Morrison. The Morrison over wide areas cannot be older than middle or late upper Jurassic in age. It is probable that some of the lower beds in the southwestern areas where the Sundance is absent may be slightly older than the oldest Morrison beds which directly overlie the Sundance. In the Black Hills area there is a time interval between the Sundance and the base of the Morrison which is represented by the Unkpapa sandstone. There is often a sharp contact between the Morrison and Sundance formations in the Wyoming areas. This indicates that the Morrison in these areas may be considerably younger than the Sundance.

The oldest beds overlying the Morrison, the age of which is definitely known, are the Washita beds near Cañon City, Colorado (Stanton, 1905, 11). The upper beds of the Morrison at this locality cannot be later than Fredericksburg in age, but may be much older. In Montana the Morrison is overlain by the Kootenie formation, which contains Comanchean plant remains, some of which are represented in the Patuxent formation in Maryland. The Kootenie apparently lies conformably on the Morrison, and it is quite probable that the Morrison and Kootenie are not distinct formations, but belong to the same deposition cycle. This question will be taken up again in considering the evidence from the vertebrate fossils.

In many areas the Morrison is overlain by the Cloverly, Lakota, or Purgatoire formations, which belong, in whole or in part, to the Comanchean period. In western Colorado the Morrison is overlain by the Dakota sandstone. The contact with the Cloverly and Purgatoire is often sharp, but there is no evidence of extensive erosion between the two formations. Erosion to a slight extent probably did take place, however. As noted by Lee, the relations of the Morrison to the overlying formations are much closer than to those beneath.

In Texas and adjoining regions, where the Morrison is absent, there is a great development of Comanchean marine deposits. Where the Morrison is present in considerable thickness, the marine Comanchean is absent or is very thin.

The evidence from the stratigraphic relations indicates, therefore, that for the *eastern areas at least,* the age of the Morrison is Comanchean rather than Jurassic.

The evidence from the flora as to the age of the Morrison is not conclusive, a number of species of cycads comprising the entire known flora. As noted above, Ward placed the age of these as Jurassic. The flora of the overlying formations has more significance and will be considered in connection with the discussion of the evidence from the vertebrates.

The invertebrate fauna has no value in determining the age of the formation. Most of the genera range from Morrison to recent time, a few being older. The species also have considerable range and are difficult to determine accurately, owing to poor preservation or lack of distinguishing characters.

The vertebrate fauna, which is one of the largest and most characteristic vertebrate faunas in any known geological formation, has often been appealed to in connection with the age of the Morrison. Marsh (1878, 2) referred the Morrison, or Atlantosaurus Beds, as he called it, to the Jurassic on the basis of evidence from the reptilian fauna. Just what this evidence consists in was never published by Marsh. He correlated the beds with the Wealden of Europe, which he considered to be Jurassic (1895, 1). In discussing the age of the Wealden he correlated it with the Morrison on the basis of its reptilian fauna, and considered it, on this evidence, to be Jurassic. It seems to the present writer that, so far as the reptilian faunas of the Morrison and Wealden were concerned, Marsh was arguing in a circle. Marsh (1896, 7; 1896, 4) quoted Seward as favoring the Jurassic age of the Wealden on the evidence of its fossil plants, and Smith-Woodward as maintaining the Jurassic age of the Wealden on the evidence from the fossil fishes. Marsh also considered the Sauropoda of the Potomac beds to be more primitive than those of the Morrison, and from this judged the Morrison to be younger than the Potomac.

Hatcher (1903, 4) held that the reptilian fauna of the Morrison was closer to that of the middle Jurassic of Europe than to the Wealden.

Lull (1911, 8), discussing the reptilian fauna of the Arundel formation, said: "The character of these dinosaurs, and of the crocodile as well, correlates the beds wherein they are found absolutely with the Morrison (Como) of the West. An accurate comparison with European formations is more difficult, as the faunas have fewer forms in common. *Pleurocœlus* is reported from the Kimmeridgian as well as from the Wealden, but that from the former horizon may readily have been ancestral to the Arundel type, although the European material is too fragmentary to admit of a just comparison. Of the other dinosaurs, the affinities seem to be entirely with Wealden forms, *Cœlurus* being found therein, while *Allosaurus* compares in point of size and dentition with the Wealden *Megalosaurus*. *Dryosaurus* has its nearest European ally in *Hypsilophodon*, again a Wealden type, and the crocodile, *Goniopholis*, is reported from the Wealden and its marine equivalent, the Purbeckian, not from the older Jurassic levels.

"The weight of this evidence would seem to place this fauna beyond the Jurassic into the beginning of Cretaceous times."

The most complete comparison between the Morrison and corresponding vertebrate faunas has been made by Williston (1905, 4), and the following is extracted from his paper:

"*Cetiosaurus longus* Owen is from the Great Oölite, or Middle Jura; *C. glymptonensis* Phillips, imperfectly known, is from the same horizon; while *C. brevis* Owen, also imperfectly known, is from the Wealden, but is referred by Seeley to *Ornithopsis*, by Lydekker to *Morosaurus*. *Ornithopsis* Seeley is from the Wealden; *O. humerocristatus* Hulke, from the Kimmeridge. Other uncertain forms are from the Wealden of England. *Titanosaurus* is referred by Lydekker to probable Upper Greensand.

Remains of the Sauropoda are spoken of as 'frequent' in the Wealden, while from the Middle Jura only a few are known, and all these are of one, or at most two, species. I certainly cannot see what evidence these forms present that would lead one to say that the American forms are clearly Jurassic. The range of this suborder, so far as is known, is from the Middle Jurassic to the Upper Cretaceous, though there may be doubt as to the real age of the Indian form. Their known geographic distribution is Europe, India, Madagascar, Africa, South and North America—that is, over the whole world. The generalized characters presented by them are not at all sufficiently well understood to say off-hand that certain forms are older than others. . . .

"It is quite true that the Brachiosauridæ of Riggs (*Brachiosaurus* Riggs and *Haplocanthosaurus* Hatcher) have a more generalized structure in this respect than has *Cetiosaurus* even, but we have no reason to assume that all the generalized forms died out with the advent of specialized ones, such as are most of the American Sauropoda. Nor do I think it quite certain that the Brachiosauridæ are the most generalized, certainly not if the hypothesis that the Sauropoda have been derived from primitive ornithopoda is at all probable. Furthermore, the genus *Pleurocœlus*, originally described from the Potomac beds, has been recognized in the Atlantosaurus beds by Marsh, and later by Hatcher, and forms from the Wealden have been referred, provisionally at least, to the same genus.

"For the most part, the carnivorous dinosaurs have little value in the correlation of the horizons. *Megalosaurus* is reported from Europe from the Lias to the Wealden. In America we have three or four genera of the Megalosauridæ in the Atlantosaurus beds, *Creosaurus, Allosaurus, Antrodesmus*, and *Ceratosaurus*, and the family survived to the Laramie Cretaceous. *Cœlurus* was described from the Atlantosaurus beds, but is known to occur in the Potomac beds. In the Wealden of England *Aristosuchus* is very closely allied, indeed is supposed to be identical, and all the other genera referred to the Cœluridæ are from the Wealden. In the extensive hollowness of the bones of the skeleton, *Cœlurus* is not only the most specialized of dinosaurs, but of all vertebrate animals. The evidence then to be derived from the Theropoda is for the contemporaneity of the Wealden with the Atlantosaurus beds.

"So far from the evidence of the Iguanodontia being against this correlation, I believe that it is decidedly for the identity of the two horizons. Iguanodonts are found in abundance in the Atlantosaurus beds, and of the largest size and high specialization. . . . And, so far from the American forms being the most generalized, Lydekker says that *Hypsilophodon* is 'the smallest and least specialized member of the family!' Perhaps this opinion is not decisive, but *Hypsilophodon* certainly cannot be called the most specialized. Lydekker even refers certain Kimmeridge and Wealden species to the American genus *Camptosaurus.*

"Perhaps the best evidence we have for the Jurassic age of the American deposits is that of *Stegosaurus,* which is so closely allied to *Omosaurus* Owen from the Kimmeridge that Marsh believed the two genera to be identical. On the other hand, this type of the predentate dinosaurs seems to range from the Lower Lias in *Scelidosaurus* to *Paleoscincus* from the Laramie, with four or five genera referred to the group from the Wealden. Its value, then, is slight.

"Other evidence offered by the reptiles from the American beds is slight. A genus of crocodiles called by Marsh *Diplosaurus* seems to include *Hyposaurus vebbii* Cope from the Comanche Cretaceous of Kansas. Years ago Zittel referred both of these forms to the genus *Goniopholis* from evidence communicated by Professor Marsh, and *Goniopholis* is said to be 'a genus very characteristic of the Wealden' (Lydekker). The recently published figure of the type specimen of *Diplosaurus,* when compared with figures of *Goniopholis,* shows a startling resemblance. Indeed, so far as I can learn, there are no brevirostral crocodiles known from below the Purbeck or lithographic slates. The evidence, then, of the crocodiles is decidedly for the uppermost Jurassic or Wealden age of the American beds.

"Of the Chelonia the single species *Compsemys plicatulus* Cope (*Glutops ornatus* Marsh) is not at all decisive. If the species is correctly referred to *Compsemys,* all its related forms are of Cretaceous age. Nor is there any evidence to be obtained from the pterosaurs or birds. Of the mammals I will not venture to speak, save that I think that there are too few forms known from the Wealden to offer any basis of comparison. Of the fishes a few species of *Ceratodus* only are known, and inasmuch as this genus is supposed to range from the Trias to the present time, these species have no correlating value whatever.

"To sum up: there is no valid vertebrate evidence pointing to an age greater than the Purbeck for the Atlantosaurus beds, and but very little for a greater age than that of the Wealden.

Unfortunately, in most of the discussions hitherto the Atlantosaurus beds have been considered as some brief epoch. The faunas of the upper and lower parts have never been differentiated, save in some exceptional cases. Marsh, indeed, rarely ever gave any precise location for his type specimens, referring them simply to Wyoming, Colorado, etc. The term 'Upper Jurassic' has been applied indiscriminately to the whole fauna.

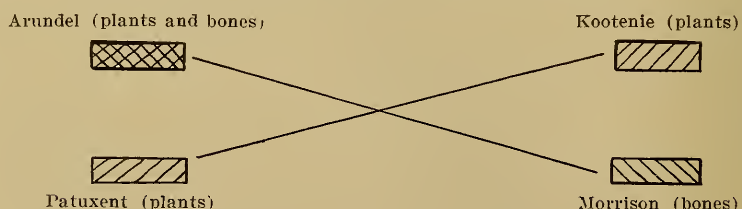
. . . Hatcher was the first to distinctly point out that the uppermost part of the beds might include a part of the Lower Cretaceous. . . .

"I am strongly of the opinion that these deposits, nowhere, so far as known, exceeding a thickness of 500 feet, really represent various epochs between the Jurassic and the Upper Cretaceous, and that sooner or later we shall have evidence to distinguish the later from the earlier faunas. . . .

"The upper part of the Atlantosaurus beds is, it seems to me, indisputably Cretaceous; the lowermost part is probably not older than the Wealden, though possibly of Purbeckian age. I therefore strongly protest against the common usage of referring all the fossils from these beds to the upper Jura. Until more is known of the different faunas contained in it, the only proper designation for the composite faunas included in them is Jura-Cretaceous; this assumes that the Wealden is really Jurassic."

A sauropodan coracoid was discovered by Larkin (1910, 2) in the Trinity formation in Oklahoma. There is no Morrison present at this locality, but it is possible that the bone had been transported some distance.

Berry (1911, 7) has discussed the three divisions of the Potomac formation and their floras at some length, and has shown that the floras of the Patuxent and Arundel beds, which have many forms in common, are closely allied to the flora of the Kootenie formation. "The two floras [Patuxent-Arundel and Kootenie] have a great many elements in common, and upon the basis of the floras alone the conclusion would be reached that the base of the Kootenie was approximately the same age or slightly older than the base of the Patuxent." The Patuxent formation, however, which contains a larger flora than the Arundel, lies below the Arundel, which contains the Morrison fauna. In the west this condition is reversed; the Kootenie, which contains a flora very closely allied to that of the Patuxent-Arundel series, lies above the Morrison with its fauna. This relation is shown by the following diagram:



The conclusion seems to be that the Kootenie and Morrison are practically the same thing, and that the Patuxent and Arundel are very closely related. Berry gives the correlation of Morrison-Kootenie together approximately equalling the Patuxent-Arundel.

Lee (1915, 2) has recently given strong diastrophic evidence for the Comanchean age of the formation.

The evidence for Comanchean age of the Morrison seems much stronger than that for Jurassic age. The interval between the Sundance and the Washita is a long one, and the Morrison may not occupy the whole of it, but only the upper portion. It is probable that the Morrison is not of exactly the same age throughout the whole area of its occurrence, and it is very improbable that every particular bed in a given locality necessarily has a corresponding bed in some other locality. The Morrison is the product of a slow accumulation process, and therefore may fill a considerable part of the interval between the Sundance and Washita. The most probable condition is that the greater part of the Morrison is Comanchean in age, with Jurassic members in its lower portion in some areas. It is possible also that in the southwestern areas the base of the Morrison is much lower than in the eastern areas, and may include considerable Jurassic.

ORIGIN AND INTERPRETATION OF THE MORRISON FORMATION

Summary of Characters

In the preceding pages many facts regarding the Morrison formation have been recorded. A number of these which may have a bearing on the question of the origin and geologic significance of the Morrison are here briefly summarized:

1). The Morrison has a very wide distribution. As noted in the summary of the stratigraphic relations of the formation, the area which is now underlain by the Morrison probably covers several hundred thousand square miles, and its original area, before being exposed to the extensive erosion which occurred in the Rocky Mountain region at the end of Cretaceous time, probably amounted to four or five hundred thousand square miles and perhaps more.

2). Considering the vast area occupied by the formation, it is very thin. The greatest thickness reported is something like 900 feet, but it is usually very much less than that.

3). The thickness is variable over large areas, and to a lesser extent in small areas. In the southwestern areas the thickness varies from 400 to 900 feet; in the northwestern areas the actual thickness and variation are both somewhat less; in the eastern and central Wyoming areas the thickness is usually about 200 feet, but in some cases it is as high as 300 or as low as 150 feet; in the Black Hills area the thickness is never more than 200 feet, and ranges from that down to zero, averaging about 100 feet; in the southeastern Colorado and New Mexico areas the thickness varies from 400 to 200 feet. It will be seen from this that while there is a considerable variation in individual areas, the *thickness is much greater in the western areas than in the eastern, and that there is a thinning out eastward, which is very gradual considering the distances involved.*

4). The size of grain of the sediments varies to a considerable extent. Fine-grained material is the most abundant; a considerable amount of medium-grained material is present, with a smaller amount of coarse-grained rock. Very coarse sediment does not appear to be present. Coarse material is more abundant in the western than in the eastern areas.

5). The succession of beds varies greatly from point to point, but the kind of succession is practically the same in every locality. Fine joint-clays or grits usually make up the greater part of the outcrops, especially toward the top. Sandstone and nodule layers are usually present at intervals in the section, and often thin limestones or occasionally conglomerate beds. These various members are found to be arranged in a certain order in one locality, and in another locality not far away the succession will be different. Sandstone beds that are thick in the first section may be thin or absent in the second. Limestone beds present in a certain position in the first section may be in another position in the second section, or absent altogether. On studying the various sections of the formation a constant thinning and thickening or replacement of individual members is to be seen. An examination of the sections in the stratigraphic division of this paper will emphasize the prevalence of the conditions above described. This type of succession in many sections has been described by Lee as "uniformly variable."

6). The contacts of the various members with each other is usually sharp, showing rather rapid changes of conditions of deposition. Beds of fine grits or clays are often followed directly by beds of medium-grained sandstone and vice versa.

7). Channeling is often present, certain layers lying in troughs eroded in the underlying beds. This has been discussed in the section on structures.

8). Cross-bedding is common in the Morrison. Both the stream and wind types have been observed.

9). The principal mineral ingredient in the Morrison sediments is quartz. Other materials usually or often present are calcite, kaolin, iron oxides, mixed carbonates, gypsum and feldspar. Mica and volcanic ash are present in very small amounts.

10). The larger quartz grains are usually well rounded; the smaller ones are often angular.

11). The iron oxides usually occur as interstitial material between fine quartz grains, and sometimes as a staining of fine-grained binding matter. In some cases it is uniformly distributed, and in other cases it is scattered in patches.

12). The limestones are thin, often very pure calcite or dolomite, and consist almost entirely of very fine-grained material. They are sometimes argillaceous and sandy.

13). The sandstones are often nearly pure quartz; when fine-grained they sometimes have interstitial materials of iron oxides, kaolin and mixed carbonates; when coarse they are often extremely calcareous, and sometimes arkosic.

14). The arkosic sandstones usually occur near the base of the formation. They are occasionally found in the middle beds, and are rare near the top.

15). The color of the rocks of the formation varies greatly, often in short distances, so that the formation was formerly called the "Variegated Beds." This variegated character is sometimes present in a hand specimen. There is often a pronounced color banding in the formation.

Gray and purplish red are the usual colors, but green, white, blue, yellow and black are also often present, and all these colors grade into each other in a complex fashion.

16). The coarse sandstones are usually gray or white. The finer clays and grits may be either green, gray, white, blue, red or dark brown. The green clays are often finer than the red or brown grits.

17). The flora of the formation is of such a nature as to indicate a warm and moist climate at the time of deposition, in some areas at least. This flora is not especially abundant, however.

18). The invertebrate fauna consists of fresh-water types. They belong to genera having a wide geologic range.

19). The vertebrate fauna is composed of aquatic, amphibious, terrestrial and aërial forms. The fish were aquatic, of course. The habitat of the sauropod dinosaurs has been the subject of controversy; some writers have held that they were exclusively terrestrial, others that they were exclusively aquatic, and still others that they were amphibious. The latter theory seems the most probable. They certainly possess aquatic adaptations, but they also possess adaptations for walking on land, in some forms at least. The crocodiles were amphibious and probably the turtles as well. The theropod and predentate dinosaurs were terrestrial, and probably the mammals as well. No marine vertebrates have been found in beds which have been definitely identified as Morrison.

20). The skeletons of the large dinosaurs often indicate, to a certain extent, by their preservation, some of the physical processes connected with their burial. In some cases, of which the Bone Cabin Quarry near Medicine Bow, Wyoming, is an example, the bones of many individuals and species are found mixed up in an intricate manner, so that anything like a complete skeleton is rare. In other cases complete or nearly complete skeletons are found in position. In still other cases a skeleton will be found complete up to a certain point and then end suddenly, with not a bone to be found beyond in any direction.

The mixed-up bones indicate that they were gathered together from their original resting-places by current action, in a restricted area, such as one individual stream. The complete skeletons indicate swift burial in relatively quiet waters or by wind action. The partial skeletons point toward erosion of the beds they were deposited with, after their burial.

21). The Morrison is more closely related to the overlying than to the underlying formations.

22). The contact with the overlying beds is sharp in places, and indicates a change of depositional conditions. There may have been a small amount of erosion of Morrison beds prior to the deposition of the overlying beds in places, but if so it was probably slight.

23). In Texas, where the Morrison is absent, its place in the stratigraphic column is occupied by great thicknesses of marine Comanchean beds.

24). In the north the Morrison is overlain conformably by the Kootenie formation. The Kootenie is similar in character to the Morrison, and part of it, at least, may belong to the Morrison. The flora of the Kootenie and Potomac formations have a bearing on this question, which has been discussed in the section on the age of the Morrison.

25). The formation lies on beds of various ages, from Archean to upper Jurassic.

26). There is a widespread erosion plane beneath the Morrison over most of its area. The relation to the Sundance will be discussed later.

27). The formation is present in isolated areas in the Rocky Mountains in Colorado, about midway between the eastern and western Colorado areas.

History of Previous Opinions as to the Origin of the Formation

The origin of the Morrison formation has been the subject of considerable attention in the past. Some of the more important discussions are noted at this point. Their merits will be discussed later.

C. A. White (1886, 2) in discussing the Morrison and its invertebrate fauna came to the following conclusions: "The character of the strata in which these fresh-water Jurassic fossils were found, both at the Colorado and at the Wyoming localities, in addition to the character of the fossils themselves, is such as to indicate for them a lacustrine, and not an estuary or a fluviatile, origin; that is, the rocks are regularly stratified and have such an aspect and character as to indicate that they were deposited in one or more large bodies of water. If the strata of the Colorado and of the Wyoming localities really contain an identical fauna, it may be regarded as probable that they were deposited in one and the same lake. The distance between the Colorado and the Wyoming localities indicates that the supposed lake was nearly 200 miles across; and, if the Black Hills fossils also belonged to the same contemporaneous fauna, the assumed lake was much larger."

Riggs (1901, 4) described the Morrison of the Grand River Valley, and gave an interpretation of the history of deposition as follows: "Let us attempt to trace the history of the Jurassic formation as evidenced by the nature of the rocks, the stratigraphy and the occurrence of fossils: Given an arm of the Jurassic sea, fed by rivers and open to the ebb and flow of tide waters. Under these conditions the sediments washed down by the river everywhere accumulated slowly, and alternating with them thin ledges of limestone and gypsum were laid down. Occasional strata of sand accumulated by the action of the retarded currents about the estuaries of streams. Later, by some change in levels, the ingress of seawater was cut off, but the outlet still remained and so ensued the gradual change from salt to fresh water. Then followed a period of comparatively uninterrupted deposition in which the green shale was laid down under still water. Along with it were deposited near the mouths of streams the occasional homogeneous beds of green sand. As the basin filled up and its outlet deepened, the lake became shallower until its bed was invaded by the shifting channels of broad and shallow streams. Its sand-bars have formed the cross-bedded sandstone ledges which mark the transition from the lower to the upper clays. With the shallower waters came the great land and shore reptiles and about the estuaries of streams their remains were deposited abundantly.

"Again the lake waters invaded the region and the deposition of sand in this locality was cut off. The period following was one of greater changes and probably of slower deposition than that preceding the river period. The presence of fine reeds or sedges shows that the water was shallow, at least in places, and parts of skeletons found on irregular surfaces imbedded in these reedy clays suggest mud-bars or islands, on which they have stranded. In one instance part of a skeleton found imbedded in a stratum of blue clay which thinned out and was replaced by sandstone with pebbles at the base, indicates that the carcass was buried in a mud-bank bordering a stream or water-current. The interruption of the vertebral column and the displacement of the ribs in one direction show that the stream was sufficient to carry away the missing part of the skeleton.

"The tendency toward a more shaly nature and the presence of carbonaceous matter in the upper measures indicate the return of shallows and the greater abundance of vegetable matter. This condition evidently culminated in the great influx of sand laden with deciduous leaves which marks the period represented by the Dakota sandstone."

Loomis (1901, 6) discussed the Morrison in the Como Bluff region. He referred to the beds as "non-marine Jura," and later in the same paper stated that the shore line, which was about 30 miles south of Como Bluff during Shirley or Sundance time, moved 100 miles to the south at the beginning of Como or Morrison time, and that the deposits were then laid down in shallow water; also that "the bones [of dinosaurs] are clearly floated out to sea by the presence of considerable meat on them." There is thus an element of contradiction in Loomis's interpretation.

Hatcher (1903, 4) discussed the origin of the Morrison at some length. As his conclusions are closer to those of the present writer than those of any of the other workers mentioned, the important parts of his discussion will be quoted at this point.

"I can fully agree with Dr. White as to the necessity of assuming the existence in Jurassic times of a continental land-mass of the dimensions intimated in his paper. But it does not seem to me at all necessary to presuppose the existence of a Jurassic lake of even the smaller or more moderate dimensions assigned by him. While I do not wish to be understood as denying the possibility of the existence of a great lake in Jurassic times extending as Dr. White has suggested from the Arkansas River in Colorado to the Black Hills of South Dakota, it does appear to me that our present knowledge of the character of the faunas, both terrestrial and aquatic (fresh-water) as well as of the lithologic and stratigraphic features exhibited by the beds themselves is decidedly against such a presumption. If I properly understand Dr. White he finds nothing in the character of the aquatic mollusca to preclude the possibility of their having lived and developed in smaller lakes. After a personal examination of the localities at Green River, Utah, at Grand River in western Colorado, Cañon City and Morrison in eastern Colorado, Como and Sheep Creek in southern Wyoming, at the Spanish Mines in eastern Wyoming, along the Bighorn Mountains in central Wyoming, about the Black Hills in South Dakota and in the country near Billings in southern Montana, in all of which localities the *Atlantosaurus beds* are exposed and exhibit in more or less abundance, the remains of those dinosaurs which are characteristic of them, I am convinced that neither the character of the vertebrate fauna nor the facts of stratigraphy at any one of these places can be taken as affording anything like conclusive evidence of the presence of a great body of water. At several of these localities, however, the occurence at intervals of sandstones showing frequent examples of cross-bedding, ripple-marks and even occasionally exhibiting footprints is conclusive proof that such sandstones had not their origin in the midst of a great lake, while the presence almost everywhere of the remains of terrestrial reptiles and less frequently of mammals tells only too plainly of an adjacent land-mass. In all this region I know of no locality where any considerable extent of the Atlantosaurus beds occurs, in which remains of quadrupedal, terrestrial dinosaurs have not been found. . . . An hypothesis, which it appears to me is far more reasonable and more nearly in accordance with the facts as we now know them, is to consider this region as presenting in late Jurassic and early Cretaceous times the appearance of a low and comparatively level plain, with numerous lakes, both large and small, connected by an interlacing system of river channels."

Chamberlin and Salisbury (1907, 7) assign a fluviatile origin to the Morrison formation.

Lee (1915, 2) considers the Morrison to be largely fluviatile in origin.

Discussion of Previous Theories of the Origin of the Formation

The theory of deposition of the Morrison in a great lake, as advanced by C. A. White, does not seem to be supported by evidence now available. The following list of characteristics of beds of lacustrine origin has been given by Johnson (1903, 8) :

1). No great variations in texture and composition in vertical section.

2). No beds of conglomerate.

3). No marked and sudden variations in respect to the thickness and areal extent of the component beds.

4). Few unconformities of erosion.

5). No extensive cross-bedding at high angles.

6). A lacustrine rather than a land fauna or flora.

The Morrison departs widely from every one of these six characteristics except the last. The fauna might be considered lacustrine in part, but some of it, if not most of it, is strictly terrestrial, and much of the aquatic element may be fluviatile as well as lacustrine.

The series of events given by Riggs might fit very well a restricted area of the Morrison deposits. The Morrison is an extremely widespread formation, however, and this fact must be continually kept in mind in discussing its origin. There does not appear to be any evidence sufficient for concluding that the lower beds of the Morrison are marine, and deposition in estuaries is not in accord with the vast distribution of the formation.

There is abundant evidence for alternating lake and river conditions in restricted areas, however, and no doubt such conditions were common.

The statement by Loomis that the dinosaur bones had floated out to sea by means of meat on them is not supported by the known facts, as there is no evidence whatever of marine conditions in the Morrison formation itself.

Hatcher's theory of a low level plain, with lakes and interlacing streams, fits the observed conditions much better. The interpretation given in the present paper is in some senses an amplification of this idea.

Preliminary Statement of Present Interpretation

To the present writer the best explanation of the origin of the Morrison formation appears to be that of a number of large streams issuing from a mountainous area and crossing a very broad flat plain. Such streams would deposit much of their loads on their flood-plains in the forms of very flat alluvial fans. Deposition by distributaries, aided by tributaries and æolian action, would tend to unite these fans into a broad alluvial plain. The main streams and tributaries consequent on the plain would gradually extend such alluvial deposits over a very broad area. In local basins between the principal stream areas and in abandoned stream valleys lakes would probably form locally. In these lakes fine sediments would be deposited, with sandstones around the margins. Æolian deposits would probably form to a certain extent between the main stream areas also.

The presence of a Comanchean sea in Texas and other areas east of the Morrison area, shown by the presence of marine sediments, indicates that part of the Morrison may be a true delta formation.

With conditions such as those above outlined kept in mind as a working hypothesis, it is desirable to consider the characteristics of large alluvial fans and river flood-plains of recent and Pleistocene origin.

Characteristics of Recent Alluvial Plains

Davis (1898, 6) describes the fan of the Hoangho River in China as follows: "One of the largest alluvial fans in the world is that of the Hoangho, in eastern China. This great river, bearing a heavy load of fine silt from the basins among the inner mountains, issues from its inclosed valley 300 miles inland from the present shore-line, and at a height of about 400 feet above sea-level, and then flows to the sea down the gentle slope of its extensive fan." The fan is fertile and is subject to overflow on a vast scale. A single flood in 1887 covered 50,000 square miles and drowned at least 1,000,000 people. The course of the river and its tributaries is constantly shifting.

The fan of the Yangtse-Kiang lies immediately south of that of the Hoangho and is more or less connected with it. The large rivers leave the mountains in valleys which resemble estuaries in their form and relation to the mountains. The mountains may be compared to the land and the plains and valley to the sea and estuary. The great rivers are bordered on either side by lakes, swamps and other streams, which often connect with each other in an intricate manner. The lakes vary in size from small ponds to large lakes 50 miles or so in length. They are usually situated in tracts along the borders of the large rivers, but are sometimes situated far from the latter. They extend from the mountains to the delta and are not especially characteristic of any one region. These features are well shown on the German government's land survey maps of eastern China (1903, 9, 10; 1904, 9, 10, 11).

Grabau (1914, 6) describes the dry delta of Cooper Creek as extending over an area of 185 x 170 miles. Grabau describes the great alluvial plain of the Indo-Gangetic region as follows:

"The Indo-Gangetic alluvial plain is an example of a river plain formed of many confluent dry deltas and carried forward by the two great rivers of northern India—the Indus on the west and the Ganges, with the tributary Brahmaputra, on the east. Numerous small streams feed these rivers from the south slope of the Himalayas, carrying an abundance of coarse and fine debris. . . . The great alluvial plain extends over an area of about 300,000 square miles, and comprises the richest and most populous portion of India. It varies in width from 90 to nearly 300 miles, and entirely separates the lower peninsula of India from the Himalayas to the north. It rises 924 feet above the sea in its highest portion, and the deepest boring has located these deposits at a depth of nearly a thousand feet below the present sea-level. . . . It abounds in gravels and conglomerates near the sloping borders, but lutaceous or clayey deposits, more or less arenaceous, prevail over much of the plain, especially near the center, with only subordinate deposits of sand, gravel, and conglomerates. Beds of blown sand of great thickness are found in some regions. . . . Shells of river and marsh molluscs are occasionally found, and calcareous concretions and nodules of irregular shape, locally known as *kankar,* are frequent. . . . Calcareous tufas also form conglomerates in the stream beds by cementing pebbles derived from the hills. In the clays along the borders and in the shoals of the Jumna River a great variety of vertebrate remains has been found, including elephant, hippopotamus, ox, horse, antelope, crocodile and various fish." Grabau gives further descriptions of these deposits, much of which would apply to the Morrison.

Lakes are not especially abundant on these plains, though some are present. The large rivers are braided in a complicated manner. An interesting feature is shown in the delta portion of the Ganges, where a large tributary, the Brahmaputra, joins the main river *below* the point where one of its largest delta distributaries, the Hooghly, is given off. These features are shown on any large map of India.

Grabau also gives a description of the Nile flood-plain. Extracts from this description are here quoted.

"A striking example of a flood-plain is afforded by that of the Nile, which flows from a well-watered region through a desert country without receiving a tributary for a thousand miles, except a few small wet weather streams. Entrenched beneath the desert uplands this flood plain holds its own for a length of 500 miles, and maintains a width of from 5 to 15 miles, broadening on the delta to over 100 miles. The annual inundation of the flood plain is caused by the northward movement of the belt of equatorial rains in summer. The flood begins in June and usually rises 25 feet or more at Cairo in the late summer or early autumn. The annual addition of the river silt causes a slow rising of the entire flood plain estimated to amount to 4½ inches a century.

"This region furnishes an instructive example of widely varying contemporaneous deposits within the same general area. On the one hand occur the drifting, cross-bedded, well rounded and pure quartz sands of the desert, and, on the other, the extremely fine, well-stratified muds of the river flood plain."

Grabau makes the following statement regarding flood-plain sediments: "From the nature of the deposits on river flood plains, perfect and often very fine stratification is to be expected. This may be considered as characteristic of typical flood plains." The Po, Ganges and Hoangho are given as examples. Davis (1900, 9) states that the proportions of fine to coarse materials in these rivers is very great.

In general, levelness of surface is a characteristic of flood-plains; the material may vary from coarse to fine, the former usually occurring in greater abundance near the source and the latter at a distance from the

FIG. 94.—*A tributary of the Grand River, near Mack, Colorado.*
Streams of this character were probably abundant in the Morrison area during the deposition of the formation.

source; and overlap away from the source of supply is characteristic. The strata deposited will often approach horizontality over considerable areas. Thinning out and replacement of beds is common. Footprints and similar structures are often found.

Color of Sediments

In moist or pluvial climates with moderate vegetation, the soil is apt to be bluish. Vegetation prevents a high degree of oxidation. "In seasons of dryness, when the amount of vegetation is small, the iron of the sediments of deltas and alluvial fans may become thoroughly oxidized.

Where dryness prevails for most of the year, and where vegetation is as a result scanty, such oxidation may be especially favored. Thus semiarid or even desert regions would furnish the best conditions for such oxidation. On river flood plains there is always sufficient moisture to result in the formation of hydroxides of iron, and hence the colors of such deposits will range from yellows to ocher and brown. It is only under conditions of intense heat that dehydration will result with a consequent change in color toward the reds. Such change of color may, however, take place as the result of aging of the deposits, as pointed out by Crosby" (Grabau, 1914, 6). Crosby's statement is as follows: ". . . the color of the deposit, so far as it is due to ferric oxide, is, other things being equal, a function of its geological age. . . . In other words, the color naturally tends with the lapse of time to change from yellow to red; and, although this tendency exists independently of the temperature, it is undoubtedly greatly favored by a warm climate" (1891, 3). Barrell has also discussed the causes of color combinations in continental sediments (1912, 10).

Without discussing the literature on this subject any further, the following conclusions may be made regarding the origin of beds of various colors in the Morrison formation. As noted above (p. 159), the coarser beds are usually gray or white, these beds often being cross-bedded, while the finer beds are green, gray, white, blue or red. The red and reddish-brown beds are not extremely fine, however, like the greenish clays. This is probably due to the prevalence in them of quartz grains, while the green clays are often composed largely of kaolinic material. There is a considerable amount of gradation of color in the finer beds. The coarser sands were probably deposited in the streams and as deltas in the lakes. The finer red, brown and gray grits were deposited in both lakes and streams, and also along river flood-plains. In most cases it would be difficult to assign one of these brownish-red grits to a precise origin. As noted above in discussing the petrographic characters of the formation, the green clays often grade into red and brown, and there is distinct evidence of the origin of some of the red color, at least, by the alteration of iron carbonate. It is possible, of course, that some of this oxidation may have taken place before the burial of the material. It is much more probable, however, that the process has been going on during a long period of time subsequent to the burial of the deposits, and in some cases is still going on. Many beds have been completely oxidized, there being little but quartz and red-stained clayey matter in the rock. This material is usually more abundant in the upper members of the formation than in the lower. Other beds show the operation to have progressed to a considerable extent, but not completed. If the process is not interfered with by diastrophism, or other violent disturbance, it is probable that oxidation will continue and red color will be produced more and more, *up to the limits set by the nature of the material.* Pure quartz sands or kaolinic clays without iron cannot be oxidized to hematitic red beds under ordinary conditions. The iron will have to be introduced from outside. This probably accounts for the absence of red color in many of the very fine green clays.

Interpretation of the Morrison Formation

From the foregoing facts recorded concerning the Morrison formation, from the conditions which are known to prevail on modern flood-plains, alluvial fans and deltas, and from previous knowledge regarding the distribution of land and sea in western North America in Mesozoic times, an attempt will be made to interpret the Morrison formation and to trace the history of parts of western North America during middle Mesozoic time.

At the close of the Triassic period certain areas in western North America were elevated. This is shown by the presence of folding in Triassic rocks which are overlain unconformably by later beds and by disconformable contact with Jurassic beds. Large areas near the Pacific Coast were greatly affected and, as the effects are visible in eastern Colorado and New Mexico, the elevation was probably widespread. Erosion progressed over the greater part, at least, of the western United States until a peneplain was developed. Over this peneplain the sea advanced in late Jurassic time, as shown by Logan (1900, 10), coming from the Pacific through Alaska and western Canada, and extending south into the United States and covering practically the same areas that are occupied by the states of Montana, Wyoming and Utah, with very slight extensions into other states. The beds deposited at this time, or at any rate part of them, now constitute the Sundance formation. In areas where these marine deposits were not laid down, such as most of western Colorado, continental sediments were laid down. These continental sediments may be represented by parts of the La Plata sandstone. Beds with Sundance fossils overlie the La Plata in some areas, however, so it is not possible to correlate these formations directly.

As the deposits immediately overlying the Sundance are of continental origin in every area which has been described, possibly excepting the Unkpapa sandstone of the Black Hills region, and it is probable that this also is continental, it is evident that the sea withdrew from the Rocky

Mountain area before the deposition of the Morrison formation, or perhaps before the deposition of the Morrison formation of certain regions in the eastern part of its distribution area. Whether this retreat took place immediately after the deposition of the beds now constituting the highest members of the Sundance formation, or whether post-Sundance marine beds were deposited and eroded before the deposition of the Morrison, is a rather difficult question to decide. It is probable that there was a time interval between the deposition of the highest Sundance beds and lowest Morrison beds in the eastern area.

In the southwestern Morrison area the McElmo appears to overlie the La Plata sandstone conformably. In some localities, however, such as near Green River, Utah, and in northeastern Utah, the McElmo or its representative, the continental part of the Flaming Gorge, overlies the marine Jurassic of Sundance age. It is probable that the continental sedimentation which produced the larger part of the La Plata sandstone was interrupted by the invasion of the Sundance sea. If any area where the La Plata had been deposited was not covered by this sea, and there appears to be such, and if this area was in connection with the source of material to the westward, it is probable that continental deposition continued without any extensive break from La Plata into lower McElmo time. In areas in Colorado, east of the southern Sundance sea in Utah, the La Plata sedimentation was suspended for the time being; whether erosion of the Colorado area took place at this time is difficult to determine. The Colorado La Plata probably never extended very far to the east at any time. Possibly slight erosion took place over the Colorado area, but not enough to make any sharp erosion contact between the La Plata and McElmo.

From the distribution of the Sundance beds, it appears probable that the Sundance sea retreated in the direction from which it advanced, exposing the southern areas first. From the nature of the contact between the Sundance and Morrison formations in the eastern areas, it appears possible that post-Sundance beds were deposited and eroded before the deposition of the Morrison. Such an interpretation certainly fits the facts known in the case, and there does not appear to be any strong evidence against it.

When the southern Utah area was laid bare by the retreat of the Sundance sea, a broad practically flat plain seems to have been left, and as the sea retreated farther and farther this plain appears to have become larger and larger, until it occupied a considerable tract in the western portion of the United States. Continental sedimentation probably began immediately after the retreat of the sea. In the southwestern areas the lowest beds of the McElmo formation probably represent this period of sedimentation. The exact geological age of these lower McElmo beds depends upon the decision of the question regarding the post-Sundance deposition and erosion. If these beds were deposited immediately after the highest Sundance, they are upper Jurassic in age; if they were deposited after a post-Sundance-pre-Morrison erosion interval, they may be upper Jurassic or basal Comanchean. To which of these two periods the lower beds of the McElmo really belong is not especially important from the point of view of the present paper.

From the greater thickness of the Morrison beds to the west, and from the larger amount of coarse material in the formation in its western occurrences, conditions which are distinctly shown in the descriptions of the formation, though there are local variations from them, it seems to the writer almost certain that the source of the materials comprising the Morrison came from mountain areas to the west of the present area of the formation.

After the lower beds of the McElmo phase of the Morrison were deposited, the formation was extended to the east, northeast and southeast. On such a plain as the one above indicated, it would be possible for a drainage system similar to that now existing in eastern China to develop. Such a drainage system, with large overloaded rivers, swamps, lakes and interlacing connecting streams was inaugurated. Æolian sedimentation no doubt accompanied the stream deposition to a certain extent. As the formation increased in thickness it also spread farther out, the upper beds overlapping the lower ones. It seems probable that the lower beds of the Morrison formation in its eastern areas are not to be correlated in age with the lower beds of the McElmo in the western areas, but are later. This extension of the formation undoubtedly took a considerable length of time. The section shown in a given locality at present does not usually represent continuous deposition in that area, but in many cases at least represents an alternation of erosion and deposition, with deposition predominating in the long run. A given thickness laid down under such conditions may represent as long a time interval as a thickness three or four times as great, or more, deposited under conditions of continuous deposition.

The Unkpapa sandstone, in the Black Hills region, may represent an æolian deposit laid down on the Morrison plain after the retreat of the Sundance sea and before the Morrison sediments had been extended to that point.

Under the conditions of alternating deposition and erosion indicated above, it would not be necessary for the beds in every section to correspond, bed for bed, or even generally, with the beds in another section. It is also reasonable to suppose that some whole sections in certain areas are slightly younger or older than other whole sections in other areas. *It appears, then, that the Morrison commenced as a continental deposit in the western areas of its occurrence in early Comanchean time (or possibly latest Jurassic), and that it spread outward as it was built up, the uppermost and easternmost beds being laid down in Comanchean time.* The upper beds are generally fine-grained as compared with the lower ones. This suggests that the mountain areas to the west were being worn down and that the streams had only sufficient gradient, on the average, to carry fine material.

The exact relation of the Morrison to the marine Comanchean is not definitely known, except that Washita beds are known, in one or two cases, to overlie the Morrison. If the above interpretation of the Morrison be anything like the truth, it seems probable that the Morrison merged into the marine deposits in the southeastern areas, such as Texas, and that the Morrison in its southeastern and eastern areas consisted of true delta deposits.

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[10] All important papers are listed, though the bibliography is not absolutely complete, especially in regard to very early papers. Works on the principles involved in the discussions in the present paper are included, as well as works dealing directly with the Morrison formation. The bibliography of the paleontology of the Morrison is not included, as it would add hundreds of titles which are of no value from the point of view of this work, being anatomical in nature. The original references to the various genera and species are given in the section on paleontology, with a few of the more important subsequent references.

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1878. 8. COPE, E. D.: "On the vertebrata of the Dakota epoch of Colorado." Paleontological Bulletin No. 28, "printed Jan. 12, 1878;" Amer. Philos. Soc., Proc., vol. xvii, pp. 233-247, 16 figs., 1878. [The Morrison is called Dakota.]

1879. 1. STEVENSON, J. J.: "Report on a special geological party operating in Colorado and New Mexico from Spanish Peaks south, field season of 1878 (and 1879)." U. S. geog. and geol. Explorations and Surveys west of the 100th meridian by Wheeler, Ann. Rep., in Ann. Rep. of the Chief of Engineers, U. S. A., for 1879, App. OO, pp. 271-281, 1879. [p. 276 mentions slight occurrence of Jura-Trias rocks; some of these may be Morrison.]

1879. 2. MILLER, S. A.: "North American Mesozoic geology and paleontology." Cincin. Soc. Nat. Hist., Journ., vol. ii, pp. 140-161, 223-244, 1879. [See also 1880, 1, and 1881, 3.] [Sections and descriptions.]

1879. 3. PEALE, A. C.: "Report on the geology of the Green River district." U. S. geol. and geog. Surv. Terr., embracing Wyoming and Idaho and portions of adjacent Territories, F. V. Hayden in charge, 11th Ann. Rep. [for 1877], pp. 509-646, 1879. [Many stratigraphic sections and descriptions, including Jurassic beds.]

1879. 4. MEDLICOTT, H. B., and BLANFORD, W. T.: A manual of the geology of India. Vol. ii, pp. 445-817, 21 pls., 1879. [Descriptions of alluvial deposits.]

1880. 1. MILLER, S. A.: "North American Mesozoic geology and paleontology." Cincin. Soc. Nat. Hist., Journ., vol. iii, pp. 9-32, 79-118, 165-202, 245-288, 1880. [See also 1879, 2, and 1881, 3.] [Sections and descriptions.]

1880. 2. NEWTON, HENRY, and JENNEY, WALTER R.: "Report on the geology and resources of the Black Hills, with atlas." U. S. geol. and geog. Surv. of the Rocky Mountain Region, J. W. Powell in charge, xv + 333 pp., 28 figs., atlas, 1880. [Many detailed sections, descriptions and discussions.]

1881. 1. STEVENSON, J. J.: "Report upon geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879." U. S. geog. and geol. Explorations and Surveys west of the 100th meridian,

G. M. Wheeler in charge, vol. iii, Geology, Supplement, 420 pp., 1 pl., 3 maps and 49 figs. Appendix by C. A. White, 33 pp., 3 pls., 1881. [Descriptions of beds, some of which are probably Morrison.]

1881. 2. HAYDEN, F. V.: Geological and geographical atlas of Colorado and portions of adjacent territories. Detailed sheets by F. M. Endlich, W. H. Holmes, A. C. Peale, A. R. Marvine and C. A. White. To accompany the 10th Ann. Rep. [for 1876] of the U. S. geol. and geog. Surv. Terr., F. V. Hayden in charge, 1881. [Maps showing the distribution of the Jurassic and "Lower Dakota" of Colorado.]

1881. 3. MILLER, S. A.: "North American Mesozoic geology and paleontology." Cincin. Soc. Nat. Hist., Journ., vol. iv, pp. 3-46, 93-144, 183-234, 1881. [See also 1879, 2, and 1880, 1.] [Sections and descriptions.]

1882. 1. HILLS, R. C.: "Jura-Trias of southwestern Colorado." Amer. Journ. Sci., 3rd ser., vol. xxiii, pp. 234-244, 1882. [General description of beds: some of these are probably Morrison.]

1884. 1. COPE, E. D.: "Tertiary vertebrata." U. S. geol. and geog. Surv. Terr., F. V. Hayden in charge, Report, vol. iii, vii + 1009 pp., 38 figs., 138 pls., 1884. [In the introduction remarks on Mesozoic stratigraphy are given. The "Camarasaurus Beds" = Wealden. Comparative faunal lists of Morrison and Wealden.]

1885. 1. EMMONS, S. F.: "Report of Rocky Mountain division." U. S. Geol. Surv., 6th Ann. Rep., pp. 62-67, 1885. [The variegated beds near Gunnison separated from the Dakota by a non-conformity.]

1885. 2. MARSH, O. C.: "On American Jurassic mammals." Brit. Assoc. for the Adv. Sci., Rep., 54th meeting, pp. 734-736, 1 pl., 1885. Geol. Mag., decade iii, vol. iv, pp. 241-247, 289-299, pls. 6-9, 1887. [General section of Mesozoic beds and descriptions of Morrison mammals.]

1886. 1. IHLSENG, I. H.: "Report on oil fields of Fremont County." Colo. Sch. Mines, Rep., 1885, pp. 75-88, 1886. [Oil present in the Morrison beds near Cañon City.]

1886. 2. WHITE, C. A.: "On the fresh-water invertebrates of the North American Jurassic." U. S. Geol. Surv., Bull. No. 29, 24 pp., 4 pls., 1886. [Descriptions and illustrations of all Morrison invertebrates known up to that time. Discussion of origin of the Morrison. The beds deposited in a great lake extending from southern Colorado to the Black Hills.]

1887. 1. LAKES, ARTHUR: "Geology of Colorado ore deposits." Colo. Sch. Mines, Rep. 1886, pp. v-xix, xxi-clix, 5 pls., 1887. [Describes strata, including the Morrison, in the introduction.]

1887. 2. LAKES, ARTHUR: "Geology of the Aspen mining region, Pitkin County, Colorado." Colo. Sch. Mines, Rep. 1886, pp. 45-84, 1 pl., 1887. [Jurassic beds, probably meaning Morrison, present.]

1887. 3. WHITE, C. A.: "On the Cretaceous formations of Texas and their relation to those of other portions of North America." Phila. Acad. Sci., Proc., vol. xxxix, pp. 39-47, 1887. [The Dakota in the Missouri Valley rests on Jurassic beds, which are absent in the Texas region.]

1888. 1. COPE, E. D.: "Mesozoic realm." Int. Cong. Geol. Amer. Comm. Rep., 1888, E, pp. 1-15, 1888. Amer. Geol., vol. ii, pp. 261-268, 1888. [Notes of fauna and stratigraphy of Jurassic (Morrison).]

1888. 2. Osborn, H. F.: "On the structure and classification of the Mesozoic mammalia." Phila. Acad. Nat. Sci., Journ., vol. ix, pp. 186-265, 30 figs., 2 pls., 1888. [Mammals from the Purbeck and Morrison formations described and discussed, the Morrison forms being referred to as Jurassic.]

1889. 1. Hills, R. C.: [Address: The field for original work on the Rocky Mountains.] Colo. Sci. Soc., Proc., vol. iii, pp. 148-164. 1889. [Suggests collecting in the Atlantosaurus beds.]

1889. 2. Stevenson, J. J.: "The Mesozoic rocks of southern Colorado and northern New Mexico." Amer. Geol., vol. iii, pp. 391-397, 1889. [Jurassic in southern Colorado consists of thin limestones; near Cañon City shales.]

1889. 3. White, C. A.: "The lower Cretaceous of the southwest and its relation to the underlying and overlying formations." Amer. Journ. Sci., 3rd ser., vol. xxxviii, pp. 440-445, 1889. [Marine origin of the Dakota shown by fossils. No Jura or Lower Cretaceous in central New Mexico. No evidence of Triassic or Jurassic seas.]

1890. 1. Cragin, F. W.: "On the Cheyenne sandstone and Neocomian shales of Kansas." Washburn Coll. Lab., Bull., vol. ii, pp. 69-80, 1890. Amer. Geol., vol. vi, pp. 233-238; vol. vii, pp. 23-33, 1890. [The Cheyenne sandstone may be equivalent to the Atlantosaurus beds or to the Trinity series.]

1890. 2. Hills, R. C.: "Additional notes on the eruptions of the Spanish Peaks region." Colo. Sci. Soc., Proc., vol. iii, pp. 224-227, 1890. [Notes the occurrence of Jurassic shales.]

1890. 3. Emmons, S. F.: "Orographic movements in the Rocky Mountains." Geol. Soc. Amer., Bull., vol. i, pp. 245-286, 1890. [Atlantosaurus beds may be Cretaceous. Term "Jura-Dakota" used. The beds are of fresh-water origin. They were deposited around various "islands" in the Rocky Mountain region.]

1890. 4. Lakes, Arthur: "Extinct volcanoes in Colorado." Amer. Geol., vol. v, pp. 38-43, 2 pls., 1890. [Notes cutting of Jurassic strata by volcanoes.]

1890. 5. White, C. A.: "The North American Mesozoic." Amer. Assoc. for the Adv. Sci., Proc., vol. xxxviii, pp. 205-226, 1890. [Atlantic Coast possesses upper Jurassic. The Potomac formation is divided. In "Interior Region" a few hundred feet of Jurassic lie conformably on the Trias; the upper part is non-marine and lower part marine. Jurassic disappears north and south, its distribution being less than that of the Trias.]

1891. 1. Cannon, George B.: "Notes on the geology of Perry Park." Colo. Sci. Soc., Proc., vol. iii, pp. 308-315, 1891. [Note on the Jura-Dakota hogback.]

1891. 2. Marsh, O. C.: "Geological horizons as determined by vertebrate fossils." Amer. Journ. Sci., 3rd ser., vol. xlii, p. 112, 1891 (abstract of paper read to the Intern. Geol. Congr.). [The Hallopus beds are Jurassic and older than the Baptanodon beds.]

1891. 3. Crosby, W. O.: "On the contrast in color of the soils of high and low latitudes." Amer. Geol., vol. viii, pp. 72-82, 1891. [Color contrast is due partly to difference in climate under which deposits were formed and also to geologic age.]

1892. 1. Weed, W. H.: "Two Montana coal fields." Geol. Soc. Amer., Bull., vol. iii, pp. 301-330, 13 figs., 1892. [Jurassic and Kootenie beds are both present at Great Falls, Montana.]

1893. 1. CANNON, GEORGE L., JR.: "The geology of Denver and vicinity." Colo. Sci. Soc., Proc., vol. iv, pp. 235-270, 1893. [Account of the early dinosaur collecting and description of the section at Morrison, Colorado.]

1894. 1. WOODWORTH, J. B.: "The relation between base-leveling and organic evolution." Amer. Geol., vol. xiv, pp. 209-235, 1894. [Review of the various theories concerning land erosion, discussion of the effect of river changes on organisms and their distribution, and the relation of the development of the Jura-Cretaceous peneplain with the contemporaneous fauna and flora, and general summary of the facts presented. Reptiles, and particularly the dinosaur group, correlated in development with the growth of the peneplain.]

1894. 2. CROSS, WHITMAN: "Pike's Peak, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 7, 7 pp., 5 maps, 1894. [Descriptions of the Morrison formation, including the Oil Creek locality. Proposal of the name Morrison.]

1894. 3. ELDRIDGE, G. H., and EMMONS, S. F.: "Anthracite-Crested Butte, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 9, 10 pp.. 8 maps, 1 section sheet, 1894. [Description of the Gunnison formation and proposal of the name Gunnison.]

1895. 1. MARSH, O. C.: "Restoration of some European dinosaurs, with suggestions as to their place among the reptilia." Amer. Journ. Sci., 3rd ser., vol. l, pp. 407-412, 1 fig., 4 pls., 1895. [Morrison equal to Wealden in age, and both are Jurassic. Restorations of Morrison dinosaurs.]

1896. 1. EMMONS, S. F., CROSS, WHITMAN, and ELDRIDGE, G. H.: "Geology of the Denver basin in Colorado." U. S. Geol. Surv., Monograph, No. 27, 556 pp., 31 pls., 102 figs., 1896. [Morrison formation deposited in a depression following Jurassic movement. The formation is Lower Cretaceous in age.]

1896. 2. MARSH, O. C.: "Vertebrate Fossils" [of the Denver basin.] U. S. Geol. Surv., Monograph, No. 27, pp. 473-527, pls. 21-31, figs. 23-102, 1896. [Notes on the Hallopus, Baptanodon and Atlantosaurus beds. The latter two are Jurassic in age.]

1896. 3. WARD, L. F.: "Some analogies in the lower Cretaceous of Europe and America." U. S. Geol. Surv., 16th Ann. Rep., pt. 1, pp. 452-463, pls. 97-107, figs. 67-69, 1896. [Comparison in detail of the Potomac and Wealden. Discussion of origin and description of the flora.]

1896. 4. WOODWARD, ARTHUR S.: "Note on the affinities of the English Wealden fish-fauna." Geol. Mag., decade iii, No. 380, pp. 69-71, 1896. [The Wealden estuary the last refuge of the Jurassic fish-fauna.]

1896. 5. MARSH, O. C.: "Age of the Wealden." Amer. Journ. Sci., 4th ser., vol. i, p. 234, 1896. [From the evidence of the fossil fishes the Wealden is Jurassic.]

1896. 6. MARSH, O. C.: "The geology of Block Island." Amer. Journ. Sci., 4th ser., vol. ii, pp. 295-298, 375-377, 1896. [Jurassic of the Potomac type present.]

1896. 7. MARSH, O. C.: "The Jurassic formation on the Atlantic Coast." Sci., N. S., vol. iv, pp. 805-816. 1896. [Evidence for Jurassic age of the Potomac deposits.]

1896. 8. Marsh, O. C.: "The Jurassic formation on the Atlantic Coast." Amer. Journ. Sci., 4th ser., vol. ii, pp. 433-447, 2 figs., 1896. [Description of the Baptanodon and Atlantosaurus beds of the west. Description of the Pleurocœlus beds and the Potomac formation. Discussion of the relative importance of fossils, the age of the Wealden and the position and character of the Jurassic.]

1896. 9. Gilbert, G. K.: "Age of the Potomac formation." Sci., N. S., vol. iv, pp. 875-877, 1896. [Discusses the methods of correlation used by Marsh in his paper on the Jurassic formation of the Atlantic Coast. Slightly favors Cretaceous age for the Potomac beds.]

1896. 10. Hill, R. T.: "A question of classification." Sci., N. S., vol. iv, pp. 918-922, 1896. [Equivalents of the Potomac extend along the Atlantic Coast and westward into Texas. Tuscaloosa equals Lower Trinity. The whole is Cretaceous. Discussion of Marsh's evidence of the Jurassic age of these beds.]

1896. 11. Marcou, Jules: "The Jura in the United States." Sci., N. S., vol. iv, pp. 945-947. 1896. [Potomac formation Jurassic in age.]

1897. 1. Haworth, Erasmus: "Underground waters of southwestern Kansas." U. S. Geol. Surv., Water Supply Paper, No. 6, 63 pp., 12 pls., 2 figs., 1897. [Map and discussion of Jura-Trias beds. Red beds were deposited in ocean water.]

1897. 2. Gilbert, G. K.: "Pueblo, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 36, 7 pp., 16 figs., 6 maps, section sheet, illustration sheet, 1897. [Discussion and sections of Mesozoic strata, including the Morrison.]

1897. 3. Clark, Wm. B.: "Outline of present knowledge of the physical features of Maryland, embracing an account of the physiography, geology and mineral resources." Md. Geol. Surv., vol. i, pp. 141-228, pls. 6-13, 1897. [Upper Jurassic and Lower Cretaceous deposited in brackish water.]

1897. 4. Clark, Wm. B., and Bibbins, Arthur: "The stratigraphy of the Potomac group in Maryland." Journ. Geol., vol. v, pp. 479-506, 1897. [Descriptions of the Patuxent, Arundel, Patapsco and Raritan formations. Discussions of the relations and age of the deposits and the views of other writers. Patuxent and Arundel are Jurassic? Patapsco is Lower Cretaceous. The whole series deposited in brackish water.]

1897. 5. Scott, Wm. B.: An introduction to geology. 1st ed., xii + 573 pp., 169 figs., 13 pls., Macmillan Co., 1897. [Name "Como" given to the Morrison in southern Wyoming. The formation is assigned to the Lower Cretaceous period.]

1898. 1. Purington, C. W.: "Preliminary report on the mining industry of the Telluride quadrangle, Colorado." U. S. Geol. Surv., 18th Ann. Rep., pt. 3, pp. 751-848, pls. 103-158, figs. 66-74, 1898. [Notes on the La Plata and Gunnison formations.]

1898. 2. Spurr, J. E.: "Geology of the Aspen mining district, Colorado, with atlas." U. S. Geol. Surv., Monograph, No. 31, 260 pp., 43 pls., 11 figs., 30 atlas sheets, 1898. [Description of the Gunnison formation, part of which is correlated with the Atlantosaurus beds.]

1898. 3. Marsh, O. C.: "Jurassic formation on the Atlantic Coast." Supplement. Amer. Journ. Sci., 4th ser., vol. vi, pp. 105-115, 1 fig. 1898. [Reply to Gilbert's criticism and restatement of evidence for Jurassic age of the Potomac beds.]

1898. 4. TODD, JAMES E.: "Section along Rapid Creek from Rapid city westward. South Dak. Geol. Surv., Bull., No. 2, pp. 27-40, pls. 2-5, 1898. [Notes on the Black Hills Jurassic.]

1898. 5. MARSH, O. C.: "Cycad horizons in the Rocky Mountains." Amer. Journ. Sci., 4th ser., vol. vi, p. 197, 1898. [Notes on the Mesozoic strata of the Black Hills.]

1898. 6. DAVIS, W. M.: "Physical geography," xviii + 432 pp., 9 pls., 261 figs., frontsp., Ginn & Co., N. Y., 1898. [Discussion of river deposits. Description of the Hoangho alluvial plain.]

1899. 1. MARSH, O. C.: "Footprints of Jurassic dinosaurs." Amer. Journ. Sci., 4th ser., vol. vii, pp. 229-232, 3 figs., 1899. [Footprints found in the Morrison of the Black Hills region.]

1899. 2. DARTON, N. H.: "Jurassic formations of the Black Hills of South Dakota." Geol. Soc. Amer. Bull., vol. x, pp. 383-396, 3 pls., 1899. [Description and history of the Black Hills Jurassic beds. Beulah shales equivalent to the Morrison.]

1899. 3. CROSS, WHITMAN: "Telluride, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 57, 18 pp., 4 maps, section sheet, 3 illustration sheets, 1899. [Sections and descriptions of the La Plata and McElmo formations. These names are proposed for divisions of the Gunnison formation.]

1899. 4. CROSS, WHITMAN, SPENCER, A. C., and PURINGTON, C. W.: "La Plata, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 60, 14 pp., 4 maps, 2 illustration sheets, 1899. [La Plata and McElmo formations described and discussed.]

1900. 1. KNIGHT, W. C.: "The Wyoming fossil fields expedition of July, 1899." Nat. Geog. Mag., vol. xi, pp. 449-465, 8 pls., 1900. [Description of Como Bluff and other Morrison localities.]

1900. 2. KNIGHT, W. C.: "Jurassic rocks of southeastern Wyoming." Geol. Soc. Amer., Bull., vol. xi, pp. 377-388, pl. 23, 1900. [Detailed sections, map, descriptions and faunal lists.]

1900. 3. KNIGHT, W. C.: "A preliminary report on the artesian basins of Wyoming." Wyo. Exp. Station, Bull. No. 45, pp. 107-251, 14 pls., 15 figs., map, June, 1900. [Brief description of the Morrison formation.]

1900. 4. CROSS, WHITMAN, and SPENCER, A. C.: "Geology of the Rico Mountains, Colorado." U. S. Geol. Surv., 21st Ann. Rep., pt. 2, pp. 15-165, pls. 1-22, 1900. [The La Plata is correlated with the lower part of the Gunnison, and the McElmo with the upper part, and in part with the Morrison.]

1900. 5. LOGAN, W. N.: "The stratigraphy and invertebrate faunas of the Jurassic formation in the Freezeout Hills of Wyoming." Kans. Univ. Quart., vol. ix, pp. 109-134, pls. 25-31, 5 figs., 1900. [Descriptions, detailed section and descriptions of new species of invertebrate fossils.]

1900. 6. WARD, L. F.: "Description of a new genus and twenty new species of fossil cycadean trunks from the Jurassic of Wyoming." Wash. Acad. Sci., Proc., vol. i, pp. 251-300, pls. 14-21, 1900. [Stratigraphic notes and descriptions of the cycads, which form the principal element of the Morrison flora.]

1900. 7. HILLS, R. C.: Walsenberg, Colorado, quadrangle. U. S. Geol. Surv., Geol. Atlas, Folio No. 68, 6 pp., 3 figs., 6 maps, 2 section sheets, 1900. [Description of the Morrison formation. It varies from 100 to 270 feet.]

1900. 8. WARD, L. F. (with the collaboration of Wm. Fontaine, Atreus Wanner and F. H. Knowlton): "Status of the Mesozoic floras of the United States. First paper: Older Mesozoic." U. S. Geol. Surv., 20th Ann. Rep., pt. 2, pp. 211-430, pls. 21-179, 1900. [Description of the occurrence and character of the strata and plant remains of the Trias and Jura at different localities in the United States and the characters of the genera and species.]

1900. 9. DAVIS, W. M.: "The fresh-water Tertiary formations of the Rocky Mountain region." Amer. Acad. Arts and Sci., Proc., vol. xxxv, pp. 345-373, 1900. [Discussion of flood-plain deposits and short description of Hoangho and Indo-Gangetic flood-plains.]

1900. 10. LOGAN, W. N.: "A North American épicontinental sea of Jurassic age." Journ. Geol., vol. viii, p. 241, 4 figs., 1900. [Section of the Morrison and Sundance formations, map of distribution of the Sundance, summary of sequence of events concerning the advance and retreat of the Sundance sea.]

1901. 1. DARTON, N. H.: "Preliminary description of the geology and water resources of the Black Hills and adjacent regions in South Dakota and Wyoming." U. S. Geol. Surv., 21st Ann. Rep., pt. 4, pp. 497-599, 55 pls., 28 figs., 1901. [Sections, descriptions, etc.; Beulah shales equal the Morrison.]

1901. 2. DARTON, N. H.: "Comparison of the stratigraphy of the Black Hills with that of the Rocky Mountain front range." Geol. Soc. Amer., Bull., vol. xii, p. 478, 1901. [General comparison, Morrison included.]

1901. 3. WILLISTON, S. W.: "The Dinosaurian genus *Creosaurus* Marsh." Amer. Journ. Sci., 4th ser., vol. xi, pp. 111-114, 1 fig., 1901. [Name "Atlantosaurus Beds" replaced by "Como."]

1901. 4. RIGGS, ELMER S.: "The dinosaur beds of the Grand River Valley of Colorado." Field Col. Mus. Pub. 60, Geol. Ser., vol. i, no. 9, pp. 267-275, 6 pls., 1901. [General section and description of beds. They were deposited by a combination of stream and lake deposition.]

1901. 5. HATCHER, J. B.: "The Jurassic dinosaur deposits near Cañon City, Colorado." Carn. Mus., Ann., vol. i, pp. 327-341, 5 figs., 1901. [Description of section, discussion of origin and correlation.]

1901. 6. LOOMIS, F. B.: "On Jurassic stratigraphy in southeastern Wyoming." Amer. Mus. Nat. Hist., Bull., vol. xiv, pp. 189-198, 2 pls., 1901. [Detailed sections and descriptions of the Morrison at Como Bluff and near-by localities.]

1901. 7. LEE, W. T.: "The Morrison formation of southeastern Colorado." Journ. Geol., vol. ix, pp. 343-352, 4 figs., 1901. [Detailed section and discussion of correlation of the beds in the canyons in southeastern Colorado.]

1901. 8. DARTON, N. H., and KEITH, A.: "Washington, Maryland-Virginia-District of Columbia, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 70, 7 pp., 8 maps, 1901. [Notes on the Potomac beds.]

1902. 1. DARTON, N. H.: "Norfolk, Virginia-North Carolina, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 80, 4 pp., 4 maps, section sheet, illustration sheet, 1902. [The Potomac series Cretaceous in age and estuarine in origin.]

1902. 2. DARTON, N. H.: "Oelrichs, South Dakota-Nebraska quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 85, 6 pp., 4 maps, 2 figs., section sheet, illustration sheet, 1902. [The Lakota immediately overlies the Unkpapa near Hot Springs, South Dakota. The Morrison is absent in this locality.]

1902. 3. RIGGS, E. S., and FARRINGTON, O. C.: "The dinosaur beds of the Grand River Valley of Colorado." Sci. Amer., Supp., vol. liii, pp. 22061-22062, 2 figs., 1902. [Description and discussion of the Grand River beds. They were deposited in a system of streams and lakes.]

1902. 4. FRAAS, E.: "Geologische Streifzüge durch die Prärien und Felsengebirge Nordamerikas." Württemberg, Jahreshefte des Vereins für vaterlandische Naturkunde, Stuttgart, Jahrg. lviii, pp. 65-68, 1902. [Observations on the Jurassic beds of Wyoming and their invertebrate fossils.]

1902. 5. LEE, W. T.: "The Morrison shales of southern Colorado and northern New Mexico." Journ. Geol., vol. x, pp. 36-58, 7 figs., 1902. [Detailed descriptions of the southern Morrison occurrences. The Morrison extends eastward into Oklahoma.]

1902. 6. LEE, W. T.: "Canyons of southeastern Colorado." Journ. Geog., vol. i, pp. 357-370, 12 figs., 1902. [Sections, descriptions, etc., of the Morrison and adjacent beds.]

1902. 7. LOOMIS, F. B.: "On Jurassic stratigraphy on the west side of the Black Hills." Second paper on American Jurassic stratigraphy. Amer. Mus. Nat. Hist., Bull., vol. xvi, pp. 401-407, 1 pl., 1902. [Detailed descriptions and sections.]

1902. 8. DARTON, N. H.: "Stratigraphy of the Bighorn Mountains." Sci., N. S., vol. xv, p. 823, 1902. [Brief abstract of fuller paper.]

1902. 9. HATCHER, J. B.: "Structure of the foreleg and manus of *Brontosaurus*." Carn. Mus., Ann., vol. i, pp. 356-376, 2 pls., 1902. [Notes on the levels of different quarries.]

1902. 10. SHATTUCK, GEORGE B.: "Development concerning the physical features of Cecil County." Md. Geol. Surv., vol. Cecil Co., pp. 31-62, 2 pls., 1902. [Extensive bibliography.]

1902. 11. SHATTUCK, GEORGE B.: "The geology of the coastal plain formations." Md. Geol. Surv., vol. Cecil Co., pp. 149-194, 5 pls., 2 figs., 1902. [Patuxent is Jurassic; Patapsco is Cretaceous; Arundel is absent or not differentiated.]

1903. 1. REAGAN, A. B.: "Geology of the Jennez-Albuquerque region, New Mexico." Amer. Geol., vol. xxxi, pp. 67-111, 7 pls., 1903. [Cretaceous rests directly upon Red Beds; apparently no Morrison present.]

1903. 2. LEE, W. T.: "The canyons of northeastern New Mexico." Journ. Geog., vol. ii, pp. 63-82, 14 figs., 1903. [Sections, descriptions etc. of country where the Morrison is present.]

1903. 3. DARTON, N. H.: "Preliminary report on the geology and water resources of Nebraska west of the 100th meridian." U. S. Geol. Surv., Professional Paper No. 17, 69 pp., 43 pls., 23 figs., 1903. [Sections, etc.]

1903. 4. HATCHER, J. B.: "Osteology of *Haplocanthosaurus*, with description of a new species and remarks on the probable habits of the sauropoda and the age and origin of the Atlantosaurus beds." Carn. Mus. Mem., vol. ii, pp. 1-72, 6 pls., 28 figs., 1903. [The Atlantosaurus beds, or Morrison, are Jurassic in age. They represent the result of combined erosion and deposition, the latter process being the dominant one.]

1903. 5. Smith, W. S. Tangier: "Hartville, Wyoming, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 91, 6 pp., 2 maps, 2 section sheets, 1 illustration sheet, 1903. [Short description of the Morrison formation.]

1903. 6. Stanton, T. W.: "A new fresh-water molluscan faunule from the Cretaceous of Montana." Amer. Philos. Soc., Proc., vol. lxii, pp. 188-189, 1 pl., 1903. [Discussion of the age of the Morrison formation.]

1903. 7. Ward, L. F.: "Correlation of the Potomac of Maryland and Virginia." Abst., Sci., N. S., vol. xvii, pp. 941-942, 1903. [General discussion.]

1903. 8. Johnson, D. W.: "Geology of the Cerillos Hills, New Mexico. Pt. I. General Geology." Sch. Mines Quart., vol. xxiv, pp. 303-350, 7 figs., 7 pls.; pp. 456-500, 6 figs., 10 pls., 1903. [Discussion of origin of sediments and their criteria.]

1903. 9. Tsi nan fu Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901? [Pub. 1903]. [Detailed map of part of the alluvial plain in eastern China. Shows streams interlacing in a complicated manner, many lakes and swamps on the fan.]

1903. 10. Nanking Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China [Pub. 1903]. [Map of the delta of the Yangtse Kiang. Many lakes and swamps are on it. Some of the lakes are 50 miles or more in length.]

1904. 1. Hatcher, J. B.: "An attempt to correlate the marine with the non-marine formations of the Middle West." Amer. Philos. Soc., Proc., vol. xliii, pp. 341-365, 2 figs., 1904. [The Atlantosaurus beds and the Dakota considered as the possible equivalents of the marine Jurassic and Lower Cretaceous.]

1904. 2. Jaggar, Thomas A.: "Economic resources of the northern Black Hills, pt. 1, General Geology." U. S. Geol. Surv., Professional Paper No. 26, pp. 13-41, pl. 1, 1904. [Section and short description of the Morrison.]

1904. 3. Peck, Fred. B.: "The Atlantosaur and Titanotherium beds of Wyoming." Wyoming Hist. and Geol. Soc., Proc. and Col., vol. viii, pp. 25-41, 5 pls., 1904. [Sections, stratigraphical descriptions and faunal lists.]

1904. 4. Darton, N. H.: "Newcastle, Wyoming-South Dakota, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 107, 9 pp., 4 maps, 6 figs., section sheet, illustration sheet, 1904. [Description of the Morrison.]

1904. 5. Darton, N. H., and Smith, W. S. T.: "Edgemont, South Dakota-Nebraska, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 108, 10 pp., 4 maps, 5 figs., section sheet, illustration sheet, 1904. [Description and section of Morrison.]

1904. 6. Spencer, A. C.: "The copper deposits of the Encampment district, Wyoming." U. S. Geol. Surv., Professional Paper No. 25, 107 pp., 2 pls., 49 figs., 1904. [Notes 400 feet of fresh-water Jurassic beds with limestones.]

1904. 7. Lee, W. T.: "Age of the Atlantosaurus beds." Geol. Soc. Amer., Bull., vol. xiv, pp. 531-532, 1904. [These beds can be correlated with the Lower Cretaceous of Texas.]

1904. 8. DARTON, N. H.: "Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain front range." Geol. Soc. Amer., Bull., vol. xv, pp. 379-448, 14 pls., 1904. [Many sections, descriptions and discussions. The Morrison is considered as Cretaceous in age.]

1904. 9. Peking Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901 [Pub. 1904]. [Map of part of the alluvial plain of China. Many lakes are present on it.]

1904. 10. Yi tschang fu Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901? [Pub. 1904]. [Map of part of the alluvial plain of China near the inland mountains. Lakes are present on it.]

1904. 11. Hankau Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1902 [Pub. 1904]. [Map of the portion of the alluvial plain of China which includes the divide between the Hoangho and Yangtse rivers. Many lakes, from small ponds to lakes 25 miles or more in length, are présent in broad belts each side of the main rivers. They connect more or less by small streams.]

1904. 12. OSBORN, HENRY F.: "Fossil wonders of the West, the dinosaurs of the Bone-Cabin Quarry, being the first description of the greatest 'find' of extinct animals ever made." Century Mag., vol. lxviii, pp. 680-694, 18 figs., 1904. [General account of the discovery and description of the occurrence of the remains, with some descriptions. Good figures of Morrison outcrops.]

1905. 1. CROSS, W., and HOWE, ERNST: "Red Beds of southwestern Colorado and their correlation." Geol. Soc. Amer., Bull., vol. xvi, pp. 447-498, 4 pls., 4 figs., 1905. [The McElmo, 300 to 900 feet thick, equivalent to the upper Gunnison or Morrison.]

1905. 2. KEYES, CHARLES R.: "The Jurassic horizons around the southern end of the Rocky Mountains." Amer. Geol., vol. xxxvi, pp. 289-292, 1 fig., 1905. [Diagram of relations of beds in the southern Rocky Mountain region.]

1905. 3. DARTON, N. H.: "Preliminary report on the geology and underground water resources of the central great plains." U. S. Geol. Surv., Professional Paper No. 32, 433 pp., 72 pls., 18 figs., 1905. [Extensive discussion of the Morrison and other Mesozoic formations, with many sections.]

1905. 4. WILLISTON, S. W.: "The Hallopus, Baptanodon and Atlantosaurus beds of Marsh." Journ. Geol., vol. xiii, pp. 338-350, 1905. [Hallopus beds are Triassic, Baptanodon beds are Jurassic and Atlantosaurus beds probably Cretaceous. Historical notes.]

1905. 5. DARTON, N. H.: "Sundance, Wyoming-South Dakota, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 127, 12 pp., 5 maps, 3 figs., 1905. [Sections and descriptions. The Morrison is Cretaceous.]

1905. 6. DARTON, N. H., and O'HARRA, C. C.: "Aladdin, Wyoming-South Dakota, Montana, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 128, 8 pp., 4 maps, 1 fig., 1 section sheet, 1905. [Short description of the Morrison formation.]

1905. 7. WARD, L. F.: "Status of the Mesozoic floras of the United States." Second paper. U. S. Geol. Surv., Monograph No. 48, pt. 1, text, 616 pp.;

pt. 2, plates, 119 pls., 1905. (Includes papers by Fontaine, Bibbins and Wieland. Stratigraphic notes by Wieland.) [Complete descriptions of Mesozoic plants and discussions and descriptions of their occurrence.]

1905. 8. Darton, N. H.: "Discovery of the Comanche fauna in southeastern Colorado." Sci., N. S., vol. xxii, p. 120, 1905. [Brief note.]

1905. 9. Fenneman, N. M.: "Geology of the Boulder district, Colorado." U. S. Geol. Surv., Bull., No. 265, 101 pp., 5 pls., 11 figs., 1905. [Detailed description of the Morrison at this locality.]

1905. 10. Cross, W.: "Rico, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 130, 20 pp., 5 maps, illustration sheet, 1905. [Sections and descriptions of the La Plata and McElmo formations.]

1905. 11. Stanton, T. W.: "The Morrison formation and its relations with the Comanchic series and the Dakota formation." Journ. Geol., vol. xiii, pp. 657-667, 1905. [Statement of existing knowledge of the Morrison in southern Colorado. Upper Comanchean fossils found above the Morrison at Cañon City.]

1905. 12. Huntington, Ellsworth: "The basin of eastern Persia and Sistan." Carn. Inst. Wash., Pub. 26, pp. 217-317, figs. 149-174, 1905. [Observations on the deposition of shales of various colors.]

1906. 1. Fraas, E.: "Vergleichung der amerikanischen und europäischen Jura-formation." Intern. Amerikanisten Kongress, Tag. 14, pp. 41-45, Stuttgart, 1906. [General comparison.]

1906. 2. Darton, N. H.: "Geology of the Bighorn Mountains." U. S. Geol. Surv., Professional Paper No. 51, 129 pp., 47 pls., 14 figs., 1906. [Many sections and descriptions, etc. The Morrison is Cretaceous; good distribution map.]

1906. 3. Darton, N. H.: "Geology and underground waters of the Arkansas Valley in eastern Colorado." U. S. Geol. Surv., Professional Paper No. 52, 90 pp., 27 pls., 2 figs., 1906. [Section, descriptions and discussion of the Mesozoic strata.]

1906. 4. Fisher, Cassius A.: "Geology and water resources of the Bighorn basin, Wyoming." U. S. Geol. Surv., Professional Paper No. 53, 72 pp., 16 pls., 1 fig., 1906. [Many sections and descriptions; the Morrison is Cretaceous; good distribution map.]

1906. 5. Miller, Benjamin L.: "Dover, Delaware-Maryland, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 137, 10 pp., 2 maps, 1 fig., 1906. [Patapsco is present and is Lower Cretaceous in age: Arundel and Patuxent may underlie the Patapsco.]

1906. 6. Darton, N. H.: "Bald Mountain and Dayton, Wyoming, quadrangles." U. S. Geol. Surv., Geol. Atlas, Folio No. 141, 15 pp., 7 maps, 6 figs., 1 cross-section and 2 illustration sheets, 1906. [Sections, maps, descriptions, etc., including the Morrison.]

1906. 7. Darton, N. H.: "Cloud Peak and Fort McKinley, Wyoming, quadrangles." U. S. Geol. Surv., Geol. Atlas, Folio No. 142, 16 pp., 7 maps, 1 cross-section and 2 illustration sheets. [Sections, maps, descriptions, etc., including the Morrison.]

1906. 8. Clark, W. B., and Miller, B. L.: "A brief summary of the geology of the Virginia coastal plain." Va. Geol. Surv., Geol. Ser., Bull., No. 2, pp. 11-24, 1906. [Patuxent and Arundel provisionally referred to the Jurassic.]

1906. 9. Darton, N. H.: "Geology of the Owl Creek Mountains, with notes on resources of adjacent regions in the ceded portion of the Shoshone Indian reservation." 59th Cong., 1st Sess., Sen. Doc. no. 219, 48 pp., 19 pls., 1 fig., 1906. [Section, descriptions and distribution map of the Morrison and other formations.]

1906. 10. Darton, N. H.: "The hot springs at Thermopolis, Wyoming." Journ. Geol., vol. xiv, pp. 194-200, 4 figs., 1906. [The Morrison is present at Thermopolis.]

1906. 11. Clark, W. B., and Mathews, E. B.: "Report on the physical features of Maryland, together with an account of the exhibits of Maryland mineral resources made by the Maryland Geological Survey." Md. Geol. Surv., vol. vi, pts. 1 and 2, pp. 27-281, 30 pls., 19 figs., map, 1906. [Patuxent and Arundel are Jurassic. Both were deposited in swampy areas.]

1906. 12. Wieland, G. R.: "American fossil cycads." Carn. Inst. Wash., Pub. 34, 266 pp., 50 pls., 137 figs., 1906. [Notes on the occurrence of the cycads in the Morrison beds, with complete discussion of their morphology and relationships.]

1907. 1. Cross, W.: "Stratigraphic results of a reconnaissance in western Colorado and Utah." Journ. Geol., vol. xv, pp. 634-679, 11 figs., 1907. [Description of the McElmo formation. Correlation table. McElmo equivalent to the Morrison.]

1907. 2. Weeks, F. B.: "Stratigraphy and structure of the Uinta range." Geol. Soc. Amer., Bull., vol. xviii, pp. 427-448, 6 pls., 3 figs., 1907. [600–800 feet of Jurassic present, of which 200–300 feet is limestone.]

1907. 3. Fisher, C. A.: "The Great Falls coal field, Montana." U. S. Geol. Surv., Bull., No. 316, pp. 161-173, 1 pl., 1907. [Morrison and Kootenie beds present.]

1907. 4. Darton, N. H., and O'Harra, C. C.: "Devil's tower, Wyoming, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 150, 9 pp., 3 maps, cross-section and structure sheet, 1907. [Sections, maps, descriptions, etc., of the Morrison and other beds.]

1907. 5. Shattuck, G. B., Miller, B. L., and Bibbins, Arthur: "Patuxent," Maryland, quadrangle. U. S. Geol. Surv., Geol. Atlas, Folio No. 152, 12 pp., 3 maps, 2 figs., section sheet, 1907. [Patuxent and Arundel provisionally classed as Jurassic and Patapsco as Cretaceous.]

1907. 6. Cross, W., Howe, E., and Irving, J. D.: "Ouray, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 153, 19 pp., 3 maps, 4 figs., illustration sheet, 1907. [Descriptions and maps, La Plata, McElmo and other formations.]

1907. 7. Chamberlin, T. C., and Salisbury, R. D.: Geology, Volume III. 624 pp., 269 figs. [Good description of the Morrison formation and fluviatile origin given for it.]

1908. 1. Darton, N. H.: "Paleozoic and Mesozoic of central Wyoming." Geol. Soc. Amer., Bull., vol. xix, pp. 403-470, 10 pls., 1908. [Many sections and descriptions. Morrison is Cretaceous.]

1908. 2. Keyes, Charles R.: "Geotectonics of the Estancia plains." Journ. Geol., vol. xvi, pp. 434-451, 12 figs., 1908. [The Morrison is present in eastern New Mexico.]

1908. 3. Fisher, C. A.: "Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana." Econ. Geol., vol. iii, no. 1, pp. 77-99, 1908. [The Kootenie lies apparently with perfect conformity on the Morrison.]

1908. 4. Barrell, Joseph: "Relations between climate and terrestrial deposits. Pt. II. Relation of sediments to regions of deposition." Journ. Geol., vol. xvi, pp. 255-295, 1908. [Discussion of types of sediment deposited under various conditions; notes on colors in sediments and discussion of their origin.]

1909. 1. Martin, G. C.: "The Niobrara limestone as a source of Portland cement material." U. S. Geol. Surv., Bull. No. 380, pp. 314-326, 1 fig., 1909. [The Morrison is of fresh-water origin.]

1909. 2. Gilmore, C. W.: "A new Rhynchocephalian from the Jurassic of Wyoming, with notes on the fauna of 'Quarry 9.'" U. S. Nat. Mus., Proc., vol. xxxvii, pp. 35-42, 1 pl., 3 figs., 1909. [Lists of the fauna of the Morrison formation.]

1909. 3. Spurr, J. E.: "Scapolite rocks of America." Amer. Journ. Sci., 4th ser., vol. xxv, p. 154, 1909. [Description of the Gunnison formation.]

1909. 4. Lee, W. T.: "The Grand Mesa coal field, Colorado." U. S. Geol. Surv., Bull., No. 341, pp. 316-334, 1 pl., 1909. [Section including the Gunnison formation.]

1909. 5. Darton, N. H.: "Geology and water resources of the northern part of the Black Hills and adjacent regions in South Dakota and Wyoming." U. S. Geol. Surv., Professional Paper No. 65, 105 pp., 24 pls., 15 figs., 1909. [Many sections and descriptions of Sundance, Unkpapa, Morrison and other beds.]

1909. 6. Darton, N. H., and O'Harra, C. C.: "Bellefourche, South Dakota, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 164, 9 pp., 4 maps, 1 fig. (field edition, 67 pp., 5 maps), 1909. [Descriptions, sections, etc. of Morrison and associated formations.]

1909. 7. Gilmore, C. W.: "Osteology of the Jurassic reptile *Camptosaurus*, with a review of the species of the genus and descriptions of two new species." U. S. Nat. Mus., Proc., vol. xxxvi, pp. 197-332, 15 pls., 47 figs., 1909. [Description of quarry and copies of Loomis's sections.]

1909. 8. Willis, Bailey: "Paleogeographic maps of North America." Journ. Geol., vol. xvii, pp. 203-208; 253-256; 286-288; 342-343; 403-405; 406-409; 424-428; 503-505; 506-508; 600-602; 15 figs., 1909. [Pp. 408-409; 424-425, Jura-Cretaceous maps and descriptions.]

1909. 9. Stanton, T. W.: "Succession and distribution of later Mesozoic invertebrate faunas in North America." Journ. Geol., vol. xvii, pp. 410-423, 1909. [Jurassic of the Rocky Mountain region equals Oxfordian and perhaps Callovian. The Morrison is overlain by the Kootenie at the north and by the Comanchean at the south.]

1909. 10. Henderson, Junius: "The foothills formations of north central Colorado." Colo. Geol. Surv., 1st Ann. Rep. for 1908, pp. 145-188, 6 pls., 1909. [General descriptions of the Morrison and other formations.]

1909. 11. Fisher, C. A.: "Geology of the Great Falls coal field, Montana." U. S. Geol. Surv., Bull., No. 356, 85 pp., 12 pls., 2 figs., 1909. [Correlation tables. The Morrison is present, overlain by the Kootenie.]

1909. 12. Darton, N. H., and Siebenthal, C. E.: "Geology and mineral resources of the Laramie basin, Wyoming." U. S. Geol. Surv., Bull., No. 364, 81 pp., 8 pls., 1 fig., 1909. [Sections, description and distribution map of the Morrison and other formations.]

1909. 13. Fisher, C. A.: "Geology and water resources of the Great Falls region, Montana." U. S. Geol. Surv., Water Supply Paper, No. 221, 89 pp., 7 pls., 1909. [Cretaceous, Morrison (60–120 feet thick) and Ellis formations appear to be conformable throughout.]

1909. 14. Darton, N. H.: "Geology and underground waters of South Dakota." U. S. Geol. Surv., Water Supply Paper, No. 227, 156 pp., 15 pls., 7 figs., 1909. [Sections, discussions and illustrations. Sundance and Unkpapa are Jurassic; Morrison is Cretaceous.]

1909. 15. Lee, W. T., and Girty, G. H.: "The Manzano group of the Rio Grande Valley, New Mexico." U. S. Geol. Surv., Bull., No. 389, 120 pp., 12 pls., 9 figs., 1909. [The Morrison is probably present.]

1909. 16. Henning, Karl I.: "Streifzüge in den Rocky Mountains. IV. Morrison und die Morrisonformation." Globus, Bd. xcvi, pp. 344-349, 5 figs., 1909. [Description of the Morrison formation, with discussion as to its age.]

1910. 1. Lull, R. S.: "Dinosaurian distribution." Amer. Journ. Sci., 4th ser., vol. xxix, pp. 1-39, 10 figs., 1910. [Correlation tables and discussion of the Morrison and other faunas.]

1910. 2. Larkin, Pierce: "The occurrence of a sauropod dinosaur in the Trinity Cretaceous of Oklahoma, with an introductory note by S. W. Williston." Journ. Geol., vol. xviii, pp. 93-98, 4 figs., 1910. [A morosauroid coracoid found in the Trinity sands.]

1910. 3. Schuchert, Charles: "Paleogeography of North America." Geol. Soc. Amer., Bull., vol. xx, pp. 427-606, 56 pls., 1910. [Paleogeographic maps and discussions.]

1910. 4. Cross, Whitman: "Engineer Mountain, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 171, 13 pp., 3 maps, 1 section sheet, 2 illustration sheets, 1910. [La Plata is lower Jurassic and equivalent to the lower part of the Gunnison. The McElmo is in general equivalent to the Morrison.]

1910. 5. Darton, N. H., Blackwelder, Eliot, and Siebenthal, C. E.: "Laramie and Sherman, Wyoming, quadrangles." U. S. Geol. Surv., Geol. Atlas, Folio No. 173, 17 pp., 7 maps, 1 section sheet, 1 illustration sheet, 1910. [Sections of Sundance and Morrison formations.]

1910. 6. Gale, Hoyt S.: "Coal fields of northwest Colorado and northeast Utah." U. S. Geol. Surv., Bull., No. 415, 265 pp., 22 pls. and figs., 1910. [Description of the Flaming Gorge formation.]

1910. 7. O'Harra, Cleophas: "The Badland formations of the Black Hills region." S. D. Sch. Mines, Dept. Geol., Bull., No. 9, 152 pp., 50 pls., 20 figs., Nov., 1910. [Sections and descriptions of the Jurassic.]

1910. 8. Clark, W. B.: "Results of a recent investigation of the coastal plain formations in the area between Massachusetts and North Carolina." Abst., Geol. Soc. Amer., Bull., vol. xx, pp. 646-654, 1 pl., 1910. [Patuxent, Arundel and Patapsco are all Lower Cretaceous.]

1911. 1. Woodruff, Elmer G.: "The Lander oil field, Wyoming." U. S. Geol. Surv., Bull., No. 452, pp. 7-36, 6 pls., 1 fig., 1911. [Section of Sundance, Morrison and Cloverly formations.]

1911. 2. Stone, R. W.: "Geological relations of ore deposits in the Elkhorn Mountains, Montana." U. S. Geol. Surv., Bull., No. 470, pp. 75-98, 1 pl., 1911. [Geologic section and map. Morrison is present at this locality.]

1911. 3. von Huene, F.: "Kurze Mitteilung über Perm, Trias, und Jura in New Mexico." Neues Jahrb., Beilage-Bd. xxxii, H. 3, pp. 730-739, 1 pl., 2 figs., 1911. [Sections at Morrison, Colorado, and Mesa Prieta.]

1911. 4. Jamison, C. E.: "Geology and mineral resources of a portion of Fremont County, Wyoming." Wyoming [Geol. Surv.] ser. B, Bull. No. 2, 90 pp., 14 pls., map, 1911. [Section and description of the Morrison.]

1911. 5. Clark, W. B., Bibbins, A., and Berry, E. W.: "The lower Cretaceous of Maryland." Md. Geol. Surv., vol. Lower Cretaceous, pp. 23-98, 10 pls., 1911. [The lower portion of the Potomac is Lower Cretaceous in age. Descriptions and sections of the members of the Potomac formation.]

1911. 6. Berry, Edward W.: "The lower Cretaceous floras of the world." Md. Geol. Surv., vol. Lower Cretaceous, pp. 99-151, 1 fig., 1911. [Discussion of Lower Cretaceous floras and map of their distribution.]

1911. 7. Berry, Edward W.: "Correlation of the Potomac formation." Md. Geol. Surv., vol. Lower Cretaceous, pp. 153-172, 1911. [Correlation table. Patuxent-Arundel equal to the Morrison-Kootenie and in part to the Wealden.]

1911. 8. Lull, R. S.: "The reptilia of the Arundel formation." Md. Geol. Surv., vol. Lower Cretaceous, pp. 173-187, 1911. [The Arundel fauna is Lower Cretaceous rather than Jurassic in age.]

1911. 9. Miller, B. L.: "Development of knowledge concerning the physical features of Prince George County." Md. Geol. Surv., vol. Prince George Co., pp. 24-33, 1911. [Note on the Lower Cretaceous, and extensive bibliography.]

1911. 10. Miller, B. L.: "Geology of Prince George County." Md. Geol. Surv., vol. Prince George Co., pp. 83-136, 7 pls., 1911. [Descriptions of the various members of the Potomac formation. They are all considered as Lower Cretaceous in age.]

1912. 1. Wegemann, C. H.: "The Powder River oil field, Wyoming." U. S. Geol. Surv., Bull., No. 471, pp. 56-75, 1 pl., 1 fig., 1912. [Short description of the Morrison formation.]

1912. 2. Calvert, W. R.: "The Electric coal field, Park County, Montana." U. S. Geol. Surv., Bull., No. 471, pp. 406-422, 1 map, 1912. [Description of Ellis, Morrison and Kootenie formations. Detailed section.]

1912. 3. Lee, W. T.: "The Tijeras coal field, Bernalillo County, New Mexico." U. S. Geol. Surv., Bull., No. 471, pp. 574-578, 1 pl., 1912. [Notes the presence of the Morrison formation.]

1912. 4. Stone, R. W.: "Coal near the Black Hills, Wyoming-South Dakota." U. S. Geol. Surv., Bull., No. 499, 66 pp., 7 pls., 8 figs., 1912. [Short description of the Morrison formation.]

1912. 5. Willis, Bailey, and Stose, G. W.: "Index to the stratigraphy of North America," accompanied by a geologic map of North America, compiled by the United States Geological Survey, in coöperation with the Geological Survey of Canada and the Instituto Geologico de Mexico, under the supervision of Bailey Willis and George W. Stose. U. S. Geol. Surv., Professional Paper, No. 71, 894 pp., 19 figs., large map in sections, 1912. [Descriptions and bibliographies of all important North American geological formations; correlation tables etc.]

1912. 6. Lee, W. T.: "Coal fields of Grand Mesa and the West Elk Mountains, Colorado." U. S. Geol. Surv., Bull., No. 510, 237 pp., 21 pls., 37 figs., 1912. [Map of the Grand Mesa region, with description and section of the Gunnison formation in that region.]

1912. 7. Stose, G. W.: "Apishapa, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 186, 12 pp., 3 maps, 1 illustration sheet, 1912. [Description of the Morrison formation.]

1912. 8. Jamison, C. E.: "The Douglas oil field, Converse County, Wyoming." Wyoming [Geol. Surv.], Bull., No. 3, ser. B, 50 pp., 8 pls., 1912. [Notes the presence of the Morrison formation.]

1912. 9. Jamison, C. E.: "The Salt Creek oil field, Natrona County, Wyoming." Wyoming [Geol. Surv.], Bull., No. 4, ser. B, 75 pp., 16 pls., 1 map, 1912. [Notes the presence of the Morrison formation.]

1912. 10. Barrell, Joseph: "Criteria for the recognition of ancient delta deposits." Geol. Soc. Amer., Bull., vol. xxiii, pp. 377-446, 4 figs., 1912. [Discussion of deltas and criteria for recognizing their origin and criteria for the determination of the marine, lacustrine and fluviatile origin of sedimentary deposits.]

1913. 1. Grout, F. F., Worcester, P. G., and Henderson, Junius: "Reconnaissance of the geology of the Rabbit Ears region." Colo. Geol. Surv., Bull., No. 5, pt. 1, pp. 1-57, 1 pl., 1 fig., 1913. [Brief description of the Morrison formation.]

1913. 2. Butters, R. M.: "'Permian' or 'Permo-Carboniferous' of the eastern foothills of the Rocky Mountains in Colorado." Colo. Geol. Surv., Bull., No. 5, pt. 2, pp. 61-94, 1913. [Discussion of the Morrison formation.]

1914. 1. Barnett, V. H.: "The Douglas oil and gas field, Converse County, Wyoming." U. S. Geol. Surv., Bull., No. 541-C, pp. 3-42, 1 pl., 1 fig., 1914. [Brief discussion of the Morrison formation and section.]

1914. 2. Hewett, D. F.: "The Shoshone River section, Wyoming." U. S. Geol. Surv., Bull., No. 541-C, pp. 43-67, 1 pl., 1 fig., 1914. [Description and discussion of the Morrison formation. It is 580 feet thick, which is very unusual in the northern areas.]

1914. 3. Lupton, Charles T.: "Oil and gas near Green River, Grand County, Utah." U. S. Geol. Surv., Bull., No. 541, pp. 115-133, 1 pl., 1 fig., 1914. [The McElmo formation is over 1,000 feet thick near Green River.]

1914. 4. Schuchert, Charles: "Climates of geologic time." Carn. Inst. Wash., Pub. 192, pp. 263-298, figs. 87-90, 1914. [Discussion of the prevailing climates of the various geologic periods. Morrison dinosaurs lived in a warm and moist climate.]

1914. 5. Trowbridge, Arthur C.: "A classification of common sediments and some criteria for identification of the various classes." Journ. Geol., vol. xxii, pp. 420-436, 12 figs., 1914. [Descriptions of modern sediments of various modes of origin and criteria for recognizing the same in older deposits.]

1914. 6. Grabau, A. W.: Principles of stratigraphy. 1185 pp., 264 ills., A. G. Seiler and Co., N. Y., 1914. [Extensive discussion of sedimentary processes.]

1914. 7. Cross, Whitman, and Larsen, E. S.: "Contributions to the stratigraphy of southwestern Colorado." U. S. Geol. Surv., Professional Paper 90-E, pp. 37-50, figs. 2, 3, pl. viii, 1914. [Description of McElmo formation and discussion of geological history of region concerned.]

1914. 8. Barnett, V. H.: "The Moorcroft oil field, Crook County, Wyoming." U. S. Geol. Surv., Bull., No. 581-C, pp. 83-104, 1 fig., 1 plate (map), 1914. [Separates only; bulletin not yet issued, Mar. 4, 1915.] [Section of the Morrison formation in this locality, with brief description.]

1914. 9. Barnett, V. H.: "Possibilities of oil in the Big Muddy Dome, Converse and Natrona counties, Wyoming." U. S. Geol. Surv., Bull., No. 581-C, pp. 105-117, 1 plate (map). [Separates only; bulletin not yet issued, Mar. 4, 1915.] [Note on the Morrison.]

1914. 10. Cross, Whitman, and Larsen, Esper S.: "The stratigraphic break below the Jurassic sandstone in southwestern Colorado." Abstract. Wash. Acad. Sci., Journ., vol. iv, p. 237, 1914. [The Dakota does not overlap the McElmo in Gunnison Canyon, as indicated by Peale's map of Colorado.]

1915. 1. Berry, Edward W.: "Paleobotanic evidence of the age of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 335-342, 1915 (read before the Paleontological Society December 30, 1914). [Discussion of the floras of the Potomac, Wealden and Kootenie formations and the relation of these to the Morrison. Favors Lower Cretaceous (Comanchean) age for the Morrison.]

1915. 2. Lee, Willis T.: "Reasons for regarding the Morrison as an introductory Cretaceous formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 303-314, 1915 (read before the Paleontological Society December 30, 1914). [Diastrophic criteria applied to the study of the Morrison. The formation is considered as the non-marine forerunner of the marine Cretaceous deposits.]

1915. 3. Lull, Richard S.: "Sauropoda and Stegosauria of the Morrison of North America compared with those of Europe and eastern Africa." Geol. Soc. Amer., Bull., vol. xxvi, pp. 323-334, 1915 (read before the Paleontological Society December 30, 1914). [The Morrison partly at least homotaxial with the Tendaguru dinosaur beds. The latter are not older than uppermost Jurassic and probably are early Comanchean.]

1915. 4. Mook, Charles C.: "Origin and distribution of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 315-322, 4 figs., 1915 (read before the Paleontological Society December 30, 1914). [The Morrison the product of alternate deposition and erosion; it may be both Jurassic and Comanchean in different parts.]

1915. 5. Osborn, H. F.: "Close of Jurassic and opening of Cretaceous time in North America." Geol. Soc. Amer., Bull., vol. xxvi, pp. 295-302, 1915 (read before the Paleontological Society, December 30, 1914). [Paleontologic evidence considered as of greater value than diastrophic in correlation; the Morrison probably both Jurassic and Lower Cretaceous.]

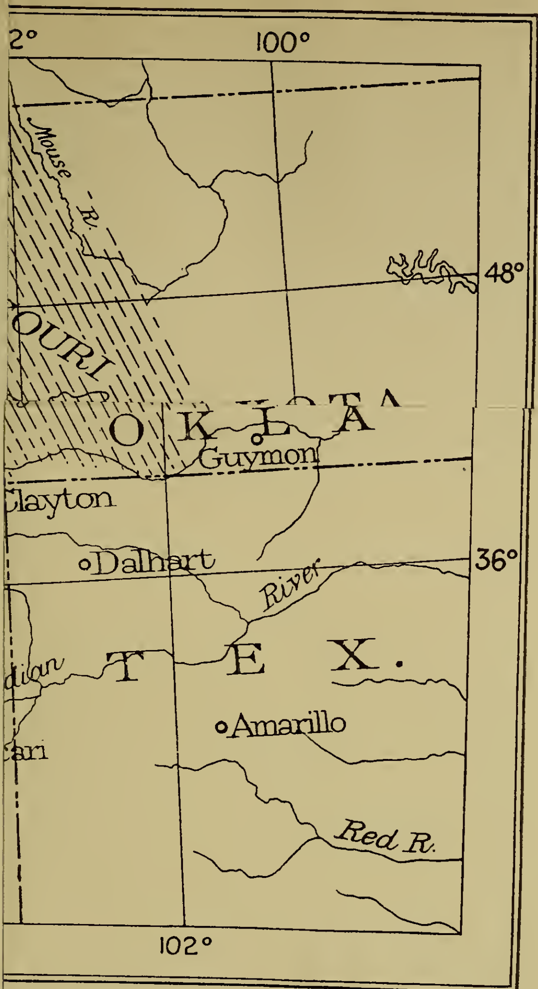
1915. 6. Stanton, T. W.: "Invertebrate fauna of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 343-348, 1915 (read before the Paleontological Society December 30, 1914). [Evidence of the invertebrates is not conclusive, but seems to indicate Jurassic age for the Morrison.]

PLATE VI

MAP SHOWING THE DISTRIBUTION OF THE MORRISON FORMATION

Heavy black lines indicate actual outcrops. Cross-hatching indicate areas where the Morrison probably lies buried beneath younger beds. Dashes indicate areas where the Morrison may or may not underlie younger beds.

NOTE.—Since the preparation of this map, Dr. W. T. Lee has informed the writer of additional outcrops in New Mexico.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FORMATION

MAP SHOWING THE DISTRIBUTION OF THE MORRISON FORMATION

Scale 0 25 50 75 100 MILES

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXVII, pp. 193–203, pll. VII–XIV

Editor, Edmund Otis Hovey

PRELIMINARY REPORT OF FOSSIL MAMMALS FROM PORTO RICO

WITH DESCRIPTIONS OF A NEW GENUS OF GROUND SLOTH AND TWO NEW GENERA OF HYSTRICOMORPH RODENTS

BY

H. E. Anthony

NEW YORK
PUBLISHED BY THE ACADEMY
9 August, 1916

THE NEW YORK ACADEMY OF SCIENCES

(Lyceum of Natural History, 1817-1876)

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[ANNALS N. Y. ACAD. SCI., Vol. XXVII, pp. 193-203, Pll. VII-XIV.
9 August, 1916]

PRELIMINARY REPORT ON FOSSIL MAMMALS FROM PORTO RICO, WITH DESCRIPTIONS OF A NEW GENUS OF GROUND SLOTH AND TWO NEW GENERA OF HYSTRICOMORPH RODENTS[1]

BY H. E. ANTHONY

(*Presented by title before the Academy, 22 May, 1916*)

CONTENTS

[1] Manuscript received by the Editor, 6 June, 1916.

INTRODUCTION

The material that forms the basis of this paper came to the American Museum of Natural History through Dr. Franz Boas, who conducted archæological investigations in Porto Rico in 1915 as part of the natural history survey of the island, undertaken by the New York Academy of Sciences with the coöperation of the Insular government. From a cave, the Cueva de la Ceiba, between Utuado and Arecibo, a number of human bones were taken and more or less intermingled with them were remains of several species of mammals. From the upper layers of the cave floor, largely a heavy deposit of ashes, came a number of bones of a new rodent genus described recently by Dr. J. A. Allen as *Isolobodon portoricensis*.[2] This part of the deposit Dr. Boas regards as artificial.[3] From deeper in the cave floor came the material under present discussion, and this formation appears to be of stalactite origin, dark red in color and of a depth of from 18 to 24 inches.

Before more extended search for additional material is made, it has seemed best to make a preliminary report on this material, leaving the finer details of the question of affinities to be discussed in a later paper. The present paper is part of the author's plan to report on the mammals of Porto Rico as his assignment in the natural history survey mentioned above.

The author wishes to acknowledge indebtedness to Mr. Gerrit Miller, Curator of Mammals in the United States National Museum, for the privilege of comparing the rodent material with the collections of fossil rodents now at Washington; and to Dr. J. A. Allen, Curator of Mammalogy and Ornithology, and to Dr. W. D. Matthew, Curator of Vertebrate Paleontology, both in the American Museum, thanks are due for valued advice and suggestions.

A list of the material is as follows:

Rostrum with one tooth, fragments of mandibular rami, part of a humerus, end of a radius, three vertebræ, one femur and part of the other, two tibiæ, portions of two fibulæ and a calcaneum, all seemingly of one individual, an unknown ground sloth.

Two fragmentary rami of different sizes, of an unknown insectivore? or bat?

A fragmentary mandibular ramus, too incomplete for present determination, of a large hystricomorph rodent.

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[2] J. A. Allen: Annals N. Y. Acad. Sci., Vol. XXVII, pp. 17-22. 25 January, 1916.

[3] J. A. Allen, *l. c.*, p. 18.

A partially complete cranium with all but one of the teeth, fragments of crania and rami and fragments of humeri, ulnæ, radii, femora, all affording more or less characters, of a large hystricomorph rodent of a genus seemingly distinct from the above.

A quite complete cranium with one mandibular ramus of a smaller hystricomorph rodent.

The anterior rostral portion of a canid skull, unquestionably an intrusion.

In addition to the above there is a small amount of uncorrelated material of fragmentary nature and also skulls and limb bones of *Artibeus jamaicensis*.

SYSTEMATIC TREATMENT

New Genus of Ground Sloth

The type of *Megalocnus* came from Cuba and consequently it is not so surprising to discover remains of a ground sloth on Porto Rico. The feature that is remarkable, however, is that the Porto Rico animal should be such a widely different type of animal. With this fact in mind, *i. e.*, that *Megalocnus* was a massive bulky animal, while the Porto Rico sloth was a much more active, less ponderous creature, I have incorporated the contrast in the following name which I offer for the new form:

Acratocnus odontrigonus[4] gen. et sp. nov.

Type, No. 14170, Dept. Vert. Pal., from Cueva de la Ceiba, near Utuado, Porto Rico, 1915; collector, Dr. Franz Boas. The skull is selected as the type.

DESCRIPTION

Skull (Plate X, Figs. 1-6; Plate XI, Fig. 1).—The skull is incomplete and shows only the rostrum back to the zygomatic process of the maxillaries, one upper tooth and several pieces, somewhat fragmentary, of the mandibular ramus.

The rostrum is elongate, rather wider anteriorly and is evenly convex from side to side above. There are no apparent premaxillaries. The canine is large, slightly curved, of decided triangular cross-section and with the worn surface seemingly much as in *Cholœpus*. The alveolus of the canine is very long and curved, reaching the plane of the posterior border of the zygomatic process on the maxillary, at which point it has attained a horizontal direction. A pair of very deep preorbital fossæ is

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[4] *Acratocnus: a,* without; *κρατυς,* robust, heavy; *"ocnus"*—meaning ground sloth without great weight. *Odontrigonus: ὀδών* = *ὀδούς*, tooth; *τριγωνος*, triangular—in allusion to the triagonal canine.

present, which reduce the palatal width at the first of the molar alveoli to less than half the width anteriorly. The palatal border of the preorbital fossa is a regularly curved line. When the skull is viewed in profile, the palate slopes rather abruptly downward posteriorly, making the rostrum much deeper at the first tooth of the molar series than it is at the canine.

Measurements of cranium: Width of rostrum just anterior to zygomatic roots, 31.5 mm.; greatest width of rostrum, at outside of canine alveoli, 36 mm.; width of palate between preorbital fossæ, 13 mm.; width of palate between canines, 13 mm.; length of palate back to first molar alveolus, 28 mm.; greatest antero-posterior extent of preorbital fossa, 23 mm.; greatest vertical depth of fossa, 16 mm.; width of canine just below worn surface, 11 mm.; thickness of canine, antero-posteriorly, same point, 9 mm.

Mandibular ramus.—The rami are fragmentary, pieces of both sides and the symphysial junction being found, but give the following characters (see Plate X, Figs. 3-6):

The ramus is deep with a wide ascending portion. The molar alveoli are deep and of large size. The canine alveolus is three sided to match the condition found in the maxillary. The canines are large, apparently of nearly the same size as the upper canines, flaring apart externally but meeting at the roots. There is no space for a very wide median symphysial tongue, but a shallow interior concavity or groove is present. The diastema between the canine and pm_4 is very short. Pm_4 and m_3 are larger than m_1 and m_2, m_3 appearing to be the largest of the series. The molars are subrectangular to roughly cylindrical in cross-section. The inferior dental foramen is large.

Measurements of ramus: Depth at anterior edge of ascending portion (approximate), 25 mm.; depth at pm_4, 21 mm.; antero-posterior width of alveolus of pm_4, 8 mm.; width of alveolus of m_2, 7 mm.; width of alveolus of m_3, 10 mm.

Humerus (Plate IX, Figs. 1-2).—Only the middle portion of a humerus (the left) was saved, but this part is sufficient to show that the bone is rather slender and much ridged for muscle attachment. The deltoid ridge is large and prominent, giving to the anterior face of the limb a very flat aspect, while there is a long sharp ridge paralleling the deltoid developed along the internal side of the humerus for attachment of the pectoralis muscle. This ridge is deep and terminates distally in a noticeable knob-like projection. A cross-section of the humerus through these two ridges would be quite rectangular in outline. There is a noticeable ridge on the inner posterior aspect of the humerus, extending downward nearly as far as the deltoid ridge, for the attachment of the latissimus and the teres major. A very large entepicondylar foramen is present. The small portion of the distal region represented in the bone indicates a thin expanded condylar region. Greatest width from deltoid to pectoral ridge, 14.5 mm.; greatest thickness of bone antero-posteriorly, at distal end of pectoral ridge, 13.5 mm.; diameter of entepicondylar foramen, 6 mm.

Radius (Plate IX, Fig. 3).—Only an end of a radius, the proximal half, was in the collection of bones. This seems to indicate a fairly straight flat element not specialized to any marked extent. Width at about the middle of the bone, 11.5 mm.; thickness at same point, 5.5 mm.

Unguinal phalanx (Plate VIII, Fig. 6).—This phalanx, of which two from the fore limbs were secured, is of a strong, compressed and moderately curved type. On the articulating surface there is a strong medial keel. Width of phalanx at a mid point, 5 mm.; depth just anterior to osseous basal knobs, 8 mm.

Femur (Plate VII, Figs. 1-4; Plate VIII, Fig. 1).—Both femurs are represented, one complete, except for a small corner of the internal condyle, the other being the distal half only. The femur is fairly robust but is not at all massive as in most of the Megalonychidæ. The shaft is not expanded but has a width considerably less throughout the mid portion than at the extremities. No great specializations are shown in the muscle attachment areas. The great trochanter does not rise above the head of the femur and there is no trochanteric fossa. There is a well developed lesser trochanter and also a quite prominent crest extending about 30 mm. along the external aspect of the femur about midway of the shaft. The condyles are large with marked tuberosities and a deep intercondylar fossa. Length, 138 mm.; greatest width across condylar portion, 39 mm.; mean antero-posterior thickness of shaft, 14 mm.; greatest width across head and great trochanter, 40 mm.; least width of shaft, about one third of distance from condyles to head, 18 mm.; head of femur, 22 mm. in diameter.

Tibia (Plate VIII, Figs. 2-4).—Both the tibiæ are complete. The tibia is but slightly curved and has a quite smooth, normal shaft. All of the facets on the two condyles are well developed. Length, 111 mm.; width across proximal head, 34 mm.; width across distal head, 26 mm.; shaft at mid portion, 13 mm. wide × 10 mm. thick.

Fibula (Plate VIII, Fig. 5).—The one nearly complete fibula, the extreme proximal end being broken off, is a slender but strong bone. It has a large articulating surface distally and proximally as well, as is shown by the well-marked facet for the proximal head of the fibula on the tibia. Length, 106 mm.; cross-section of mid portion, 5 × 7 mm.

Calcaneum (Plate IX, Fig. 4).—The well preserved calcaneum is quite large with a widely expanded free portion. The border is extensively roughened for tendon attachment. The facet for the astragulus is about 5 mm. posterior to the cuboid facet, showing that the astragulus must be of a long-necked type (no astragulus was obtained). Greatest length, 41 mm.; width of expanded portion, 30 mm.; thickness of expanded portion, 4.5 mm.; transverse width of cuboid articulation, 15 mm.; greatest width of calcaneum at anterior end, 19.5 mm.

Vertebræ (Plate IX, Figs. 5-7).—Three vertebræ were obtained—the axis, a dorsal and a caudal vertebra.

The axis has a fairly high, wide, keel-shaped neural spine and a short thick odontoid process. The neural canal is very large. Height from bottom of centrum to top of neural spine, 34 mm.; length of centrum from end of odontoid, 24 mm.; height of neural spine from roof of neural canal, 13 mm.

The dorsal vertebra bears a long spinous process set at a low angle with the vertebral column. The transverse processes are short; the ribs articulate, the tubercle with the transverse process, the head, partly with the centrum of the anterior vertebra, but to a greater extent with a facet on the wall of the neural canal of the posterior vertebra. The centrum is subtriangular in cross-section. Length of spinous process from plane of anterior margin of transverse processes, 27 mm.; height of spinous process above roof of neural canal, 12 mm.; length of centrum, 14 mm.

The caudal vertebra is peculiar in having a depressed, flattened appearance with wide transverse processes. The spinous process is low (distorted?) and the neural canal very small. There are no other noticeable projections from the body of the vertebra. This is a condition very closely approximating that found in *Cholœpus* of the Bradypodidæ. Width across transverse processes, 38 mm.; vertical thickness of centrum, posteriorly, 8 mm.; lateral width of centrum (articulating surface), posteriorly, 17 mm.

REMARKS

Acratocnus presents characters that sharply mark it off from any hitherto described forms. It seems to have no close direct affinities with any of the Megalonychidæ, but relationship, somewhat removed, is shown to several genera. Compared with the *Hapalops-Eucholœops* group of the Santa Cruz formation of Patagonia, a distant relationship may be assumed on the basis of the comparative lightness of limb bones of the *Hapalops-Eucholœops* type. *Acratocnus* is even more slender limbed than the Santa Cruz sloths, the femur of this genus, for example, being almost as long as that of *Hapalops rutimeyeri* but of less than half its breadth. However, the Santa Cruz animals are the lightest limbed, most generalized members known among the Megalonychidæ and it is among them that the nearest affinities to *Acratocnus* are found. The calcaneum of *Acratocnus* resembles very much that of *Hapalops,* and the triangular canine, characteristic of this new genus, is approximated rather closely in some species of *Hapalops. Acratocnus* seems to have no very apparent affinities with *Megalocnus* from Cuba, the former being at one extreme of the series, the lighter limbed end, the latter being at the massive limbed end of the series.

To summarize, *Acratocnus* is a form widely differing from other ground sloths in such a significant collection of characters as slender limb bones (relatively speaking), deep anteorbital fossa, triagonal canines, large molars, short diastema between c and pm_4, no pronounced median, symphysial tongue, low-spined dorsal vertebræ and depressed, expanded caudal vertebræ that its distinctness is readily apparent. Such suggestive structures as the wide caudal and the low dorsal vertebræ, the facets on the calcaneum calling for a long-necked astragulus, and the limb bones, relatively long for their width, call for a consideration of the tree sloths, the Bradypodidæ, in this connection. It is not the purpose of this paper to go deeply into such a question and the material might well be deemed inadequate for such conclusions; but it appears well within the limits of possibility that some such form as *Acratocnus* may be used eventually to throw the two families, the Bradypodidæ and the Megalonychidæ into one family. Certainly the Porto Rico sloth was not so restricted in its habitat as most of the members of the Megalonychidæ and if not in part, at least, arboreal, might readily become so.

Regarding the age of *Acratocnus,* the indications point to its being a contemporary of the Pleistocene or late Pleistocene period, quite certainly not of a much earlier time.

New Genus of Hystricomorph

The large hystricomorph rodent represented by the nearly complete skull and the skeletal portions of several individuals proves upon examination and comparison with considerable material to be worthy of a new genus and the following name is therefore proposed for it:

Elasmodontomys obliquus[5] gen. et sp. nov.

Type, No. 14171, Dept. Vert. Pal., from the Cueva de la Ceiba, near Utuado, Porto Rico, 1915; collector, Dr. Franz Boas. The type is a skull having all

[5] *Elasmodontomys:* ἐλασμὸς, a thin plate; ὀδών = ὀδούς, tooth; μῦς, mouse—referring to the thin plates of enamel that are found in the molars; and *obliquus* = oblique, these plates being not at right angles to the tooth row, as might be expected, but decidedly oblique to it.

the teeth but m^3 (right), and with the nasals and the posterior right side of the cranium broken away.

DESCRIPTION

Skull (Plate XIII, Figs. 1-3; Plate XIV, Figs. 1-4).—The skull is essentially hystricomorph in general outlines with eight molar teeth and large anteorbital fenestræ or passages for the masseter. The outline of the skull above is somewhat similar to that of *Myocastor*, flat-topped, with nasals widening anteriorly, the greatest width of the skull just posterior to the zygomatic process of the maxillary, a short sagittal crest, and a pinched-in occipital region. The incisive foramina are small and set in a deep narrow excavation in the palate. The tooth rows are divergent anteriorly and the post-palatal notch reaches to about the middle of the last molar. The bullæ are large and compressed laterally. An anterior portion of a lower jaw, probably to be associated with the type skull, indicates a deep ramus, an extensive symphysis and mandibles flaring posteriorly from the symphysis.

Dentition (Plate XIV, Fig. 2).—The teeth present the most striking characters. The incisors, two in the upper and two in the lower jaw, are long, curved and rather slender in proportion to the size of the skull. The upper incisors show no striations, but the lower incisor has two well defined grooves running the full length of the tooth and showing on the cutting edge. The incisors are deeper antero-posteriorly than broad laterally, and in the lower jaw are noticeably flattened on the inner side where each tooth meets its fellow of the opposing mandible.

The molar teeth, four in each jaw and all of nearly equal size, are made up of a succession of thin enamel plates, some of which are slightly curved, alternating with bands of dentine. The enamel plates run completely through the tooth from side to side and their edges may be seen laterally, as there is no encircling wall of enamel. There are five of these plates in all of the upper molars and in addition the last two molars have a vestige of a sixth plate. The only lower tooth in position, the first of the molar series, has five plates, and this condition prevails in a number of uncorrelated teeth, leading me to expect the lower teeth to closely resemble the upper in respect to the number of plates. The upper premolar is subtriangular in section, the three molars are quadrangular. In all the molars, both upper and lower, the plates are set at a pronounced angle to the line of the tooth row. The upper molars are set into their alveoli at an angle that makes each row of teeth flare outward from the other. Loose teeth show that this is due to a progressive curve in each molar, beginning with the premolar. The curve to m^3 is quite extreme, the convexity being pointed inward and forward. The molars probably grew throughout life, as they are rootless and of practically the same cross-section at the bottom as the top.

Measurements: Total length (approximate), 125 mm.; width, back of zygomatic process of maxillary (approximate), 46 mm.; length of nasals (estimate), 40 mm.; length of maxillary tooth row, 32 mm.; length diastema, 30 mm.; dimensions of m^2, 8×8 mm.; length diastema of lower jaw, 19 mm.; dimensions of pm_4, 6×8 mm. long.

Limb bones and trunk skeleton.—The skull of *Elasmodontomys* sufficiently establishes the distinctness of this type, and a description of the other bones found must be deferred to a later paper, making mention, however, of the fact that the limb bones are in a normal proportion to the size of the skull and are in most respects very similar to those of any hystricomorph of this size, *Myocastor* for example.

REMARKS

Elasmodontomys seems to occupy a position of its own among the hystricomorphs. At the present writing none of the accepted families of this section appear to have very strong claims upon it, and this conclusion is not a hasty one, but the result of a careful comparison with many fossil types and all of the recent forms. The molars of *Elasmodontomys* may be matched approximately in several families and among the sciuromorphs as well as the hystricomorphs, showing that to this character undue importance may not be attached, as it is a parallel evolution in these different groups. But when we couple this character, the laminate structure of the molars, to such others as are recognized hystricomorph characters, the presence of anteorbital fenestræ and four molars, for example, the search for an including family must be restricted to the following families,[6] the Cavidæ, the Chinchillidæ, the Dasyproctidæ, the Erethizontidæ and the Octodontidæ, excluding for obvious reasons the Old World hystricomorphs, and troublesome characters arise in the case of each family. Examination of the accompanying plates will demonstrate these points better than a written statement. It is not unlikely that more extended comparisons and reflections and additional material may warrant the erection of a separate family for this most interesting rodent.

As the bones of this animal were found quite well bedded in the red stalactite formation, the deeper layers of the cave deposit, its age may be assumed as at least as old as the late Pleistocene, and it is plausible to consider *Elasmodontomys* as a contemporary of *Acratocnus*.

[6] Palmer's classification: N. Amer. Fauna, No. 23, p. 782. 1904.

Second New Genus of Hystricomorph

From a layer evidently higher than that which preserved *Elasmodontomys* came the skull and mandible of a smaller hystricomorph which proves equally as interesting as its larger tomb fellow and is, like it, apparently unknown to science. As it presents characters widely different from the hystricomorphs of the Antilles and the mainland of Central and South America, I propose for it the following name:

Heteropsomys[7] **insulans** gen. et sp. nov.

Type, No. 14172, Dept. Vert. Pal., from Cueva de la Ceiba, near Utuado, Porto Rico, 1915; collector, Dr. Franz Boas. The type skull is a partially complete cranium lacking the nasals, the left zygomatic arch and the left auditory region, but with one incisor and the first two molars in each row and the right mandible with four teeth, the incisor and three molars.

DESCRIPTION

Skull (Plate XI, Figs. 2-3; Plate XII, Figs. 1-5).—The skull has the superior outline slightly curved from nasals to parietals, abruptly curved downward in occipital region. From the opening between the premaxillaries it may be seen that the nasals are narrow posteriorly, widening noticeably anteriorly. The frontals carry a peg-like postorbital process. There is a short, shallow, sagittal crest along the downward-bent portion of the cranium. Fairly large anteorbital fenestræ are present and the zygomatic process of the maxillary is broad and shelf-like. The jugal is heavy and wide, especially posteriorly, where it bears a prominent process continued posteriorly from the lower margin of the jugal. There is also a low postorbital projection at the suture of the jugal with th squamosal. A shallow excavation, surrounded by a border raised from the surface of the palate, is present partly in the premaxillaries, partly in the maxillaries, and contains the small incisive foramina at its anterior end. The foramina are not median but are widely separated. The interpterygoid fossa is carried forward into the palatines almost as far as the anterior border of the third tooth of the molar series, thus forming a very extensive V-shaped post-palatal notch. The bullæ are of moderate size, evenly rounded but slightly compressed laterally. Short parapophyses are borne by the exoccipitals. The foramen magnum is very large proportionally.

The mandible is very similar in shape to that of *Prœchimys*. The coronoid is low and narrow, there is a broad shelf-like masseteric ridge

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[7] ***Heteropsomys:*** *ἕτερος*, **different;** *ὄψ*, **aspect;** *μῦς*, **mouse—*i. e.,* mouse of a different aspect.**

and the posterior portion of the ramus is expanded and deep with a concave border.

Dentition (Plate XI, Figs. 2-3).—The teeth of *Heteropsomys* are of a highly specialized type. They are considerably worn and the primary pattern is, on this account, lost, but the crown surfaces are none the less distinctive. The incisors are small and of the ordinary curved rodent type. The molars, four in number in each jaw, are all nearly equal in size and have a prominent median lateral indentation or infolding down the side of the tooth, the fold being on the inside of the tooth above, on the outside of the tooth in the lower jaw. Within the crown surface of each tooth and more or less isolated from one another by the dentine are little hollow, flattened tubes of enamel; three in number in the upper molars (only pm^4 and m^1 present to be examined), two in the lower molars. The molars are two rooted, the roots being short truncated cones in appearance.

Measurements: Total length, 69 mm.; zygomatic width (approximate), 40 mm.; width of brain case, back of zygomatic root of squamosal, 27 mm.; interorbital width, anterior to postorbital processes, 18.5 mm.; alveolar length of maxillary tooth row, 14.5 mm.; length of diastema, 17 mm.; dimensions of m^1, 3.5 × 4 mm.; greatest length mandible, without incisor, 44 mm.; alveolar length of mandibular molar series, 15.5 mm.

REMARKS

Heteropsomys apparently requires no lengthy comparison with any known genus. Its distinctness when compared with any of the mainland hystricomorphs is immediately evident, and because of this fact it is not advisable in this paper to attempt to place it in any particular family. A possible later discovery of more material[8] in Porto Rico and a better understanding than that prevailing now of the relationships of the diverse families of the hystricomorphs is necessary in the case of *Heteropsomys* as well as in that of *Elasmodontomys.*

This rodent is doubtless of a later age than either *Acratocnus* or *Elasmodontomys,* judging from its position in the cave deposits and from the appearance of the bone itself. While one may not be justified in considering it a contemporary of *Isolobodon,* considered by Allen[9] as exterminated by the natives in recent times, at least it could scarcely have been earlier than late post-Pleistocene.

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[8] Specimens with unworn teeth may reveal points on the evolution of the molars now impossible to surmise with accuracy.

[9] ALLEN, *l. c.*, p. 22.

PLATE VII

RIGHT FEMUR OF **Acratocnus odontrigonus**

FIG. 1.—Anterior aspect (nat. size).
FIG. 2.—View of proximal end, showing head of femur (nat. size).
FIG. 3.—View of distal end, showing condylar surface (1 1/10 × nat. size).
FIG. 4.—Posterior aspect (nat. size).

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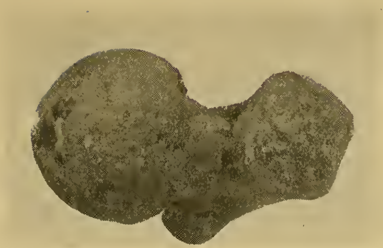

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PLATE VIII

LIMB BONES OF *Acratocnus odontrigonus*

FIG. 1.—Internal aspect of femur (nat. size).
FIG. 2.—Posterior aspect of tibia (1 1/11 × nat. size).
FIG. 3.—View of distal end of tibia (1 2/13 × nat. size).
FIG. 4.—View of proximal end of tibia (nat. size).
FIG. 5.—Posterior aspect of fibula (nat. size).
FIG. 6.—Unguinal phalanx of fore limb (nat. size).

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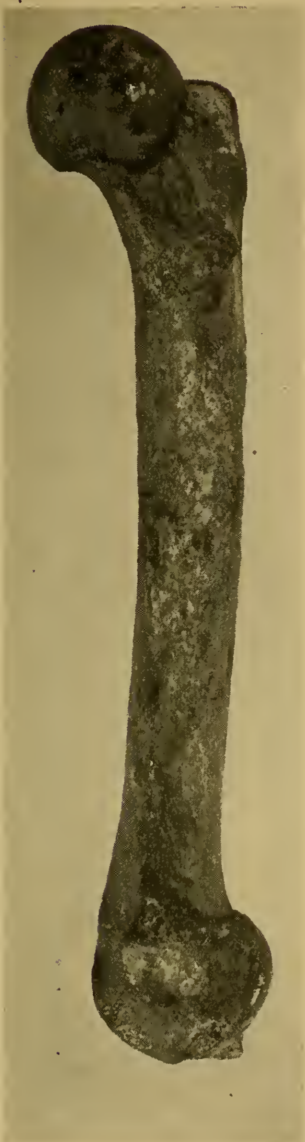

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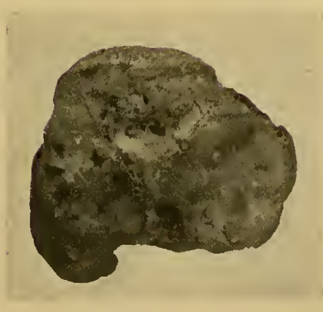

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PLATE IX

LIMB BONES AND VERTEBRÆ OF *Acratocnus odontrigonus*

FIG. 1.—Anterior aspect of left humerus (approximately nat. size).
FIG. 2.—Internal aspect of left humerus (approximately nat. size).
FIG. 3.—Proximal half of radius (nat. size).
FIG. 4.—Calcaneum, showing articulating surface (1¼ × nat. size).
FIG. 5.—Dorsal aspect of caudal vertebra (1½ × nat. size).
FIG. 6.—Lateral aspect of dorsal vertebra (1 1/7 × nat. size).
FIG. 7.—Lateral aspect of axis (1 1/12 × nat. size).

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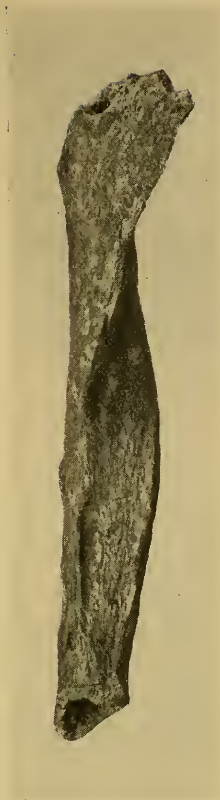

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PLATE X

SKULL OF *Acratocnus odontrigonus*

FIG. 1.—Lateral aspect of rostral portion (1 1/3 × nat. size).

FIG. 2.—Dorsal aspect of rostral portion (1 1/3 × nat. size).

FIG. 3.—Internal aspect of left mandible (approximately nat. size).

FIG. 4.—External aspect of left mandible (approximately nat. size).

FIG. 5.—Internal view of broken anterior portion of right mandible (approximately nat. size).

FIG. 6.—Median symphysial portion of mandible, showing alveoli of canines nearly meeting at base (approximately nat. size).

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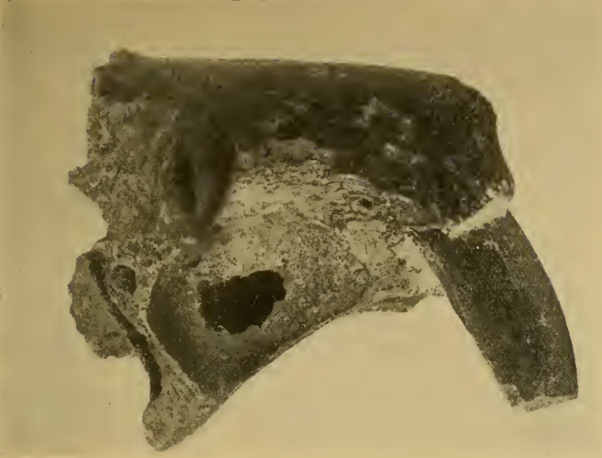

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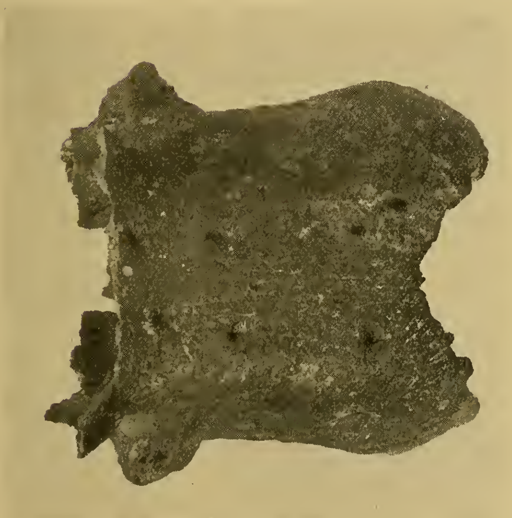

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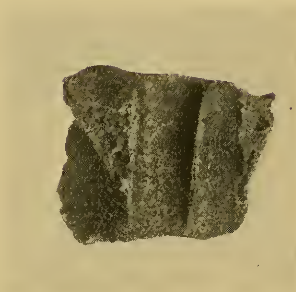

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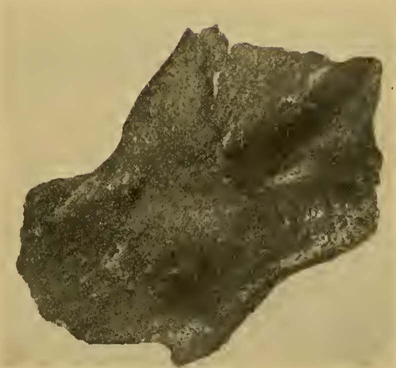

PLATE XI

SKULLS OF **Acratocnus odontrigonus** AND **Heteropsomys insulans**

FIG. 1.—Palatal view of rostral region of *Acratocnus* (1 1/3 × nat. size).

FIG. 2.—Palatal view of *Heteropsomys*, showing pattern of molar crowns (2 × nat. size).

FIG. 3.—Crown view of mandibular molar series of *Heteropsomys* (2 × nat. size).

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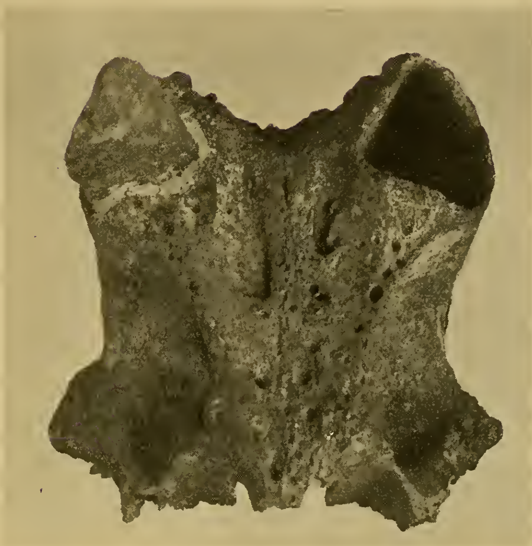

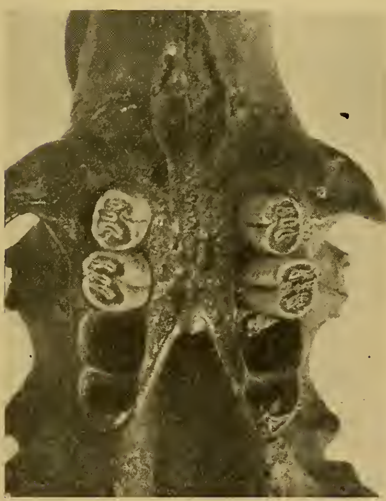

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PLATE XII

SKULL OF **Heteropsomys insulans**

FIG. 1.—Skull viewed from above (1 1/13 × nat. size).
FIG. 2.—Lateral aspect of skull (1 1/14 × nat. size).
FIG. 3.—Palatal aspect of skull (1 1/14 × nat. size).
FIG. 4.—External lateral aspect of right mandible (1¼ × nat. size).
FIG. 5.—Internal lateral aspect of right mandible (1½ × nat. size).

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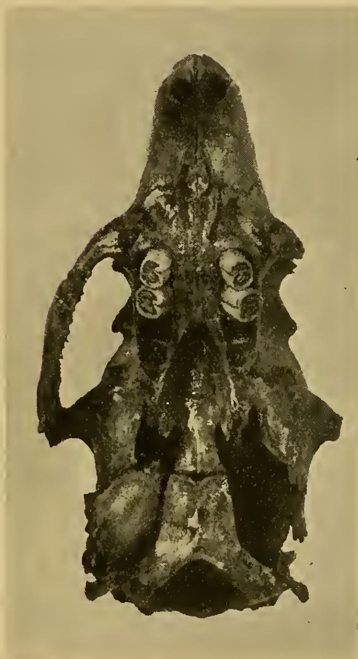

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PLATE XIII

SKULL OF **Elasmodontomys obliquus**

FIG. 1.—Palatal aspect of skull (1⅛ × nat. size).
FIG. 2.—Lateral aspect of skull (1⅛ × nat. size).
FIG. 3.—External lateral aspect of left mandible (slightly more than nat. size).

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PLATE XIV

SKULL OF **Elasmodontomys obliquus**

FIG. 1.—Skull viewed from above ($1\frac{1}{8} \times$ nat. size).
FIG. 2.—Crown view of maxillary tooth row (approximately $2 \times$ nat. size).
FIG. 3.—Skull viewed from in front ($1\frac{1}{8} \times$ nat. size).
FIG. 4.—Crown view of mandibular tooth row (approximately nat. size).

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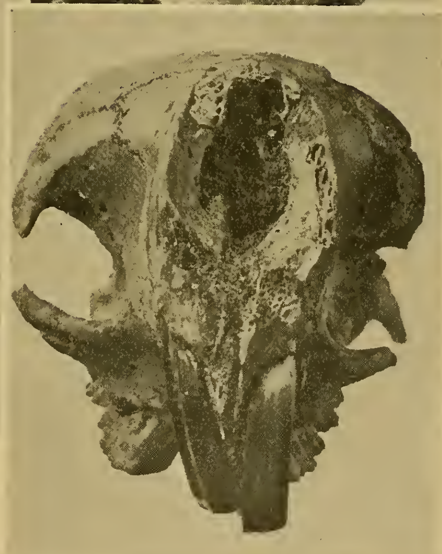

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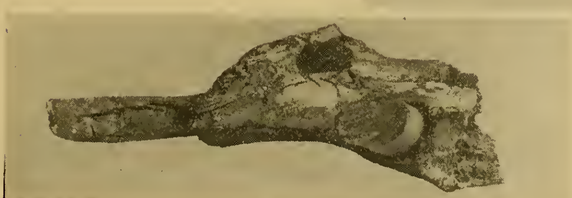

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Vol. XXVII, pp. 205–214

Editor, Edmund Otis Hovey

PHYSIOGRAPHY OF THE SKYKOMISH BASIN, WASHINGTON

BY

Warren S. Smith

NEW YORK
PUBLISHED BY THE ACADEMY
31 January, 1917

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[Annals N. Y. Acad. Sci., Vol. XXVII, pp. 205-214. 31 January, 1917]

PHYSIOGRAPHY OF THE SKYKOMISH BASIN, WASHINGTON[1]

By Warren S. Smith

(*Presented before the Academy 5 April, 1915*)

CONTENTS

Introduction

The area whose physiography is considered in the present chapter is in the Cascade Mountains of Washington, latitude 47° 40′ N., longitude 121° 40′ W., about 40 miles east of Seattle. The surface is extremely rugged and is clothed with a dense, almost impenetrable growth of underbrush or forest. But the difficulties of traversing the wooded valleys or climbing the steep mountain sides are amply repaid by the everchanging grandeurs of these alpine mountains. The valleys, too, have a wondrous charm, with their swift dashing streams and lovely lakes of cliff-inclosed water. Few trails, a single railroad and the recently constructed Cascade Highway furnish ingress to this little known part of the State. Three or four small lumbering towns in the main valley give shelter to a small population. But in summer there is an ever growing number of recreation seekers who pass a care free week or two in this mountain wonderland. The writer's home is in one of the small towns and the facts for this chapter have been accumulated during the summer months of the past few years.

Character of the Uplift

Standing on any of the needles that rise to an altitude of 5500 feet or more, one has an unobstructed view in every direction. Hundreds of

[1] Manuscript received by the Editor 21 June, 1916.

peaks of about the same elevation rise in the distance, but none high enough to cut off the vista of still more distant peaks. More than 100 miles to the north the volcanic cone of Mt. Baker and an equal distance to the south Mt. Rainier loom up into the field of one's vision as the eyes rest on the mountainous landscape. The enchanted mountaineer is impressed with the nearness of these majestic, pure white cones, and the idea occurs to him that if only one could fill the depressions between peaks, the surface would be practically level. If such a thing were actually done, the result would be what physiographers call an upraised peneplain (Fig. 1).

The existence of this peneplain is generally admitted. Russell[2] called it the "Cascade Plateau" and various subsequent writers have used the first half of the term, replacing the second with such equivalent terms as "uplift" (Willis).[3] This uplifted peneplain will be called the Cascade peneplain for the purposes of this paper.

The character of the deformation resulting in the plateau must be worked out from a study of the range as a whole, 300 square miles being too small an area in which to do more than apply such principles. These principles are two in number:

1.[4] The cause of uplift of the Cascade peneplain is to be found in compressive stress acting on materials below the outer crust, the surface deformations being incidental results of such deep-seated strains.

2.[5] The slow and gradual uplift of the peneplain was accompanied by local warpings whose parallel axes lie at an angle to the principal axis of the uplift.

Granting the first of these principles, the second needs no further proof, since any irregularity in the surface, in the competency of the rock structure or in the direction from which the pressure of deformation was applied, would result in such warpings of the surface.

The northernmost warping in the Snoqualmie quadrangle is called the Wenatchee Uplift. Trending west of north, this uplift included all of the mountains south of the Skykomish River lying in the Skykomish quadrangle. The mountains north of the Skykomish River seem to belong to a separate uplift. Weaver has called them the Skykomish Mountains (Fig. 2) and they will here be called the Skykomish Uplift.[6] The presence of the well defined Skykomish Basin, with its gentle slopes rising southward and its steeper slopes rising northward, seems sufficient evi-

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[2] I. C. Russell: 20th Ann. Report, U. S. G. S., pt. 2, p. 144.

[3] Bailey Willis: U. S. G. S. Prof. Paper 19, p. 85. 1903.

[4] *Idem:* Prof. Paper 19, 1903, p. 97.

[5] *Idem:* Prof. Paper 19, 1903, p. 97.

[6] C. E. Weaver: Bull. 7, Wash. Geol. Surv., p. 31. 1911.

Fig. 1.—*Cascade peneplain. From head of Miller River Basin.*

Fig. 2.—*Skykomish Mountains at Berlin. Skykomish River in foreground.*

FIG. 3.—*Skykomish Valley at Berlin.*

FIG. 4.—*Glacial lake. La Bohn Mountain in distance. On Foss River trail.*

dence to identify the Skykomish Uplift as a separate warping of the Cascade peneplain (Fig. 3).

Willis has shown mathematically[7] that the cause of uplift of the Cascade peneplain, of whatever nature it may be, was the result of deep-seated strain. The strain was due to a disturbance of isostatic equilibrium. This disturbance may have been due to the transfer of material eroded in the formation of the peneplain, thus decreasing the load on the peneplained block and increasing it on the adjacent block. Another possible cause of the disturbance might be found in magmatic movements resulting in the vulcanism and batholithic intrusion of the Miocene. Both of these may have acted. In the Skykomish Basin, Miocene igneous rocks are affected by the planation and are included in the uplift. Therefore the upward movement must be post-Miocene. On the other hand, the movement was pre-Pleistocene because the latter is the period of glacial occupancy. Thus by delimitation the age of the peneplain dates to the Pliocene. The fact that the plateau is maturely dissected by valleys reaching 5000 feet in depth is evidence that a considerable part of the Pliocene must have elapsed since the orogenic process began. The beginning of the uplift may then be confidently stated as early Pliocene, possibly extending to, or even into, Pleistocene.

The nature of the uplift was a regional warping of a block of the earth's crust by deep-seated forces acting principally in Pliocene time.

GLACIATION

The efficacy of glaciers as agents of erosion seems too well established to need comment. For one interested in the forms due to such erosion few localities in the United States are more favorable to their study than the Skykomish Basin. Eight small glaciers in the area, lying in two groups of four each, are lone descendants of mighty alpine glaciers that formerly crowded the valleys with slow-moving ice. These may be classified as transitional between cliff glaciers[8] and alpine glaciers. The lowest elevation to which they extend is at present about 5000 feet.

Comparatively straight, glaciated or "U" shaped valley troughs with hanging valleys from which water falls in cascades and which are often occupied by deep, narrow bodies of water are typical features of the Skykomish Basin. Truncated spurs are seen on either side of these valleys and till is found on the valley walls of the largest streams. Cirques, often with tarn lakes, abound. Serrate ridges or arêtes lead to alpine peaks of the Matterhorn type and only a little rolling, pre-glacial upland

[7] Bailey Willis: Prof. Paper 19, p. 97. 1903.
[8] Chamberlain & Salisbury: Geology, Vol. 1, p. 256. 1904.

is to be seen. All these topographical features are characteristic of an area in which alpine glaciation has been active.

The valley of the East Fork of Foss River may serve as an example of a glaciated valley (Fig. 4); one is particularly impressed with the steepness of the valley walls. In one place the valley wall rises 3000 feet in a horizontal distance of 2500 feet. The valley floor is half a mile wide and beyond this the opposite wall rises steeply again. Another excellent trough valley is the one occupied by Deception Creek. Trough lakes are numerous. The largest of the lakes of the Skykomish Basin, Lake Dorothy, is probably the best example. It lies in a hanging trough valley whose sides rise precipitately about 1500 feet on either shore of the lake. Passage along the lake shore is hazardous or impossible because of this steepness. The lake is deep and pours its waters over a solid granodiorite barrier through a narrow gorge which has apparently been cut since glacial retreat.

There are innumerable examples of cirques, such as those occupied by Malachite Lake and by Crystal Lake. The walls of these cirques rise precipitously for 1000 feet, and the sight of a score of cascades tumbling into the horseshoe-shaped basins with a mingled roar and hiss as they fall into the pools which their energy has hewn is one that once seen is forever retained as one of the magnificent memories of mountaineering. These cirques are more often than otherwise occupied by tarns, or shallow, circular bodies of water, scores of which are mapped, besides other scores which escaped the cartographer's attention.

Hanging valleys are frequent, but perhaps the finest and most picturesque example is the one occupied by Lake Katharine (Fig. 5). It hangs 1200 feet above the West Fork of Foss River. The valley is exceedingly steep-walled, and the vista opened before one standing on a commanding height at the lower end displays the whole length of the box-like valley with its extraordinarily lovely sheet of water, reflecting the snowy mountains at its head. Turning down stream one can see a narrow spillway along which the foaming water plunges to a second lake several hundred feet below, and beyond this a similar chute that gives outlet to Foss River more than 1000 feet below.

Serrate ridges and alpine peaks will be considered later. Possibly the best occurrence is the southeast trending ridge that forms the apex of the angle between the Skykomish and Beckler Rivers. Truncated spurs are well shown at S in the block diagram (Fig. 6).

Till-covered valley walls occur along the Skykomish, Beckler, Tye and Snoqualmie Rivers. Near the confluence of Martin Creek and the Tye River, this boulder clay extends 250 feet above the stream level. Its

FIG. 5.—*Lake Katharine. Glacial trough lake on Foss River drainage.*

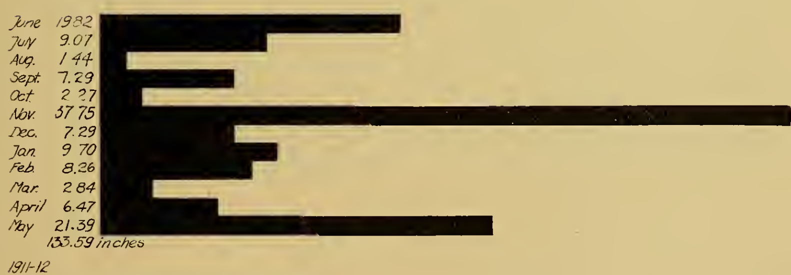

FIG. 7.—*Run off at Berlin from Miller River drainage basin. Area, 44.2 square miles.*


P
Tye Soda Granite

Fig. 6 BLOCK DIAGRAM OF A PORTION OF THE SKYKOMISH BASIN.

thickness measured perpendicular to the valley wall is variable but never great. Five miles farther west, near the confluence of Tye and Foss Rivers, glacial till occurs to an estimated height of 350 feet above the water. It is filled with boulders from the size of an egg up to great, rounded individuals weighing a ton or more. This till shows little sign of weathering and probably belongs to the last glacial advance. Bretz has described similar valley till on the Middle Fork of the Snoqualmie.[9] There is no evidence of any earlier till to be seen in the Skykomish Basin, it probably having been entirely removed by the last glacier (Vashon) that occupied the valley. At Berlin, ten miles below Martin Creek, there is blue glacial clay which occurs in lenses in the glacial till on the valley sides to a height of 500 feet above water level. Bretz has estimated the thickness of the Puget Sound Glacier, which was of the Piedmont type, originating in ice coming not alone from the Cascade Alpine glaciers, but also southward from British Columbia, at 4000 feet.[10] My own observations tend to show that the surface of the ice was about 2500 feet above sea level at Berlin. About 1000 feet of the Puget Sound ice was below present sea level. Inasmuch as considerable gradient would be necessary for ice to flow down to a confluence with the Piedmont Glacier, only something less than 3500 feet could be allowed for the thickness of this Piedmont tongue, an amount in discrepancy with Bretz's figure.

The drainage modifications due to glacial moraines were not specially studied. From observations near Berlin, however, it would appear that material deposited from the Miller River Glacier has crowded the Skykomish River to the north wall of the latter stream's valley. There are many other minor modifications, but they are of little importance.

We have seen thus far the forms of topography due to glacial erosion. Let us now consider the remnants of the mountain ridges between which the valley glacier so effectively worked. These may be considered under three divisions: first, serrate ridges; second, alpine peaks; third, preglacial uplands.

With few exceptions all the ridges are serrated. A serrate ridge or arête is produced by headward development of cirques[11] or[12] by trough widening. These leave the "fishbone" edges so characteristic of the northern Cascades. The best example in the Skykomish Basin is probably the ridge separating the West Fork of Foss River and the East Fork

[9] J. H. Bretz: "Glaciation of the Puget Sound Region," Wash. G. S. Bull. No. 8, p. 224. 1913.

[10] J. H. Bretz: "Glaciation of the Puget Sound Region," Wash. G. S. Bull. 8, p. 36. 1913.

[11] W. H. Hobbs: Characteristics of Existing Glaciers, p. 33 *et seq.*

[12] E. de Martonne: Traité de Géographie Physique, p. 622.

of Miller River. One is immediately impressed—first, with the narrowness of the ridge; second, with the roughly triangular shape of the teeth of the comb (arête), and third, with the abundance of cirques, many of them occupied by tarns, on either side. This ridge is not serrated more than normal in the district, for nearly every crest line is a narrow, jagged series of cliffs always difficult to traverse.

The trigonal pyramidal teeth, which are referred to above, are not irregularities characteristic of the ridge crest. Nearly every culminating peak of sufficient prominence to have attracted a name to itself is a pyramid terminating upward in an apex, so sharp that not more than a dozen men could occupy it at once. These points have been called "horns" in the Alps, e. g., Matterhorn, Dreieckhorn, etc. Locally they are called "hay-stacks." Usually they are accessible only from the southern slopes because the northern face is precipitous and presents from a few hundred to a thousand feet of almost vertical cliff face. It is at the foot of this northern face that the small cliff glacier exists, largely because it is there protected from the sun's heat throughout most of the day. Standing on one of these "horns" one can count a dozen others at varying distances in every direction. Certain areas at an elevation of 6000 feet are characterized by rolling surfaces which are comparatively smooth (P in Fig. 6). These are interpreted as parts of the peneplain not affected by glaciation.

DRAINAGE

The climate of the northern Cascades is temperate. In the larger valley bottoms the temperature never falls below 0° Fahrenheit, nor rises above 100° Fahrenheit, and the daily variation for weeks at a time will not be more than 10° above or below 40° Fahrenheit. The area lies in the belt of prevailing westerlies and for a preponderant portion of the seasons the air moves inland from the Pacific Ocean, after being warmed by the Japanese current. In the winter, this warm wind blowing from the southwest will melt snow with surprising rapidity and the great floods of the year result. They immediately follow the lowest stage in the river run-off—that is to say, about November 15, following the minimum run-off period of late October. In the spring, the melting of the winter's snowfall sustains the run-off well into the summer, and it is not until about July 15 that the streams begin to lose volume markedly. The months of January, February and March are those of least run-off. Such a régime has been called "alpine"[13] in Europe to describe streams rising in the high Alps and fed until midsummer by melting snows (Fig. 7).

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[13] E. DE MARTONNE: Traité de Géographie Phy., p. 356. 1909.

The southwest winds, heavily saturated with warm waters from the Japan current, are compelled to rise 7000 feet or more in crossing the Cascades. As a result of this rise the pressure of the overlying atmosphere is reduced so that the air loses density and the temperature drops. This tends to cause heavy precipitation, and in fact the moisture is so completely taken from the atmospheric currents that eastern Washington has a semi-arid climate.

Precipitation comes chiefly in the months of minimum temperature and a very large proportion of this precipitation is in the form of snow. At Cascade, a little way down the eastern slope of the Cascade Mountains, and just east of Scenic, D. C. Shafer says 110 feet of snow fell in one year.[14]

Willis tells us that the canyons of the Cascades were cut to advanced youth in the Twisp or pre-glacial stage. The canyons were over-deepened to an unknown amount by glaciation in the Chelan stage and he gives the name Stehekin to the stage succeeding glacial occupancy.[15]

Little can be said of the Twisp stage; there are but few unglaciated, elevated areas and all valley sides have been affected by glaciation. A majority of them present the straightened courses and the nearly vertical walls which are characteristic of alpine glaciation. These vertical walls rise to a height of hundreds of feet, but the pre-glacial slope beginning at the upper limit of the vertical wall has been so modified by extremely active geologic processes of ice, water and insolation that no accurate data of over-deepening are ventured in this paper, though it is probable that if the extent of such modifications could be determined more or less reliable information could be obtained.

The amount of Stehekin cutting varies with varying factors; the depth of the stream gorge of Dorothy Creek is about 40 feet and this has apparently been cut by swiftly running, but sediment free, water. Maloney Creek runs in a gorge about 80 feet deep, but here the erosion has been chiefly in Eocene sediments and by swiftly running water abundantly provided with cutting tools. The Great Falls of Miller River seem to have retreated in resistant granodiorite a distance of some 60 feet. Many other examples could be cited, but they would only show that Stehekin cutting has been comparatively slight and therefore the stage is not very far progressed. This means that at a comparatively recent time the tributary valleys of the Skykomish and Snoqualmie Rivers were occupied by glaciers.

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[14] D. C. Shafer: A Waterfall to Haul Mountain Trains. World's Work, Vol. 17, p. 10. 982. 1908-1909.

[15] B. Willis: Contributions to Geology of Washington. Prof. Paper 19, pp. 80-83. 1903.

The type of drainage in the Skykomish Basin is medium textured and its pattern is dendritic. Of the 300 square miles included, very few have no stream of mapable size, while many have as many as six. The master streams have a course oblique to the trend of the mountains. The secondary streams are parallel to the axial trend and those of lesser order are dendritic. The South Fork of the Skykomish and the Middle Fork of the Snoqualmie are the master streams.

Erosion of the Cascade Mountains had reached a mature stage before their occupancy by glaciers. These glaciers continued their work long enough to destroy nearly all the pre-glacial upland (Fig. 6) and so reach a stage of maturity. Present day drainage is largely through glacial troughs which are characterized by precipitous canyon walls, hanging valleys and some undrained swamps and numerous lakes.

Relation of Topography to Geology

We have seen that the major Cascade peneplain had warpings whose axes were oblique to the principal Cascade axial trend. Two of these warpings, which seem to be identifiable in the area under discussion, we have called the Wenatchee and the Cascade Mountains. We have seen that these warpings have a gentler slope toward the north. The possibility that the steeper slopes might be fault escarpments has been pointed out by Weaver,[16] but neither he nor any other writer have found any direct evidence of faulting and at present the unsymmetrical fold hypothesis seems more defensible.

It seems possible that some relation exists between the present drainage system and the original structure of these folds. Some future work may explain this relation, but at present insufficient information is at hand to justify any genetic classification of the rather complex drainage system.

Streams and glacial corrosion have produced many sharp peaks. The highest of these is 7986 feet in elevation and lies on the divide between the Columbia and the Puget Sound watersheds. A few other elevations reach 7000 feet or over and many lesser peaks approach this height. All those above 7000 feet are on the Cascade Divide, a condition which is not in accord with Smith's observations in the Snoqualmie Quadrangle.[17]

The relation between kind of rock and type of topography must be stated cautiously. It is notable that the higher mountains, such as Big Snow, Index and others, are in plutonic igneous rocks. But on the other hand, White Horse Mountain is in Eocene sandstone. The high peaks on

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[16] C. E. Weaver: Index Mining District, Bull. 7, Wash. Geol. Surv., p. 32. 1912.

[17] Geo. O. Smith: Contributions to the Geology of Washington, Prof. Paper 19, pp. 35 *et seq.* 1903.

the divide above mentioned are carved from the granodiorite batholith, with the possible exception of the very highest of all, which was unexplored by the writer.

There are apparently stronger grounds for stating a relation between drainage and rock type. The long, nearly straight, north and south valley, occupied in turn by Beckler River and by the Foss, is developed in Eocene sedimentaries and was very probably determined by the lesser resistance to corrosion offered by these terranes. The trend of the valley corresponds with the strike of the rock strata. It will be seen at a glance that a stream like Miller River, which is quite analogous in nearness to base level and in size of drainage basin and hence in volume, has succeeded far less strikingly in cutting its valley. The position of the master streams has no known relation to rock type.

Summary

The Cascade peneplain was up-arched in Pliocene time with a north-south axial trend. Orogenic processes resulted in unsymmetrical surface warping with an axial trend oblique to that of the main Cascade uplift. In the pre-glacial stage this was maturely dissected and in the Pleistocene, due to changed climatic conditions, was burdened with alpine glaciers. These produced a mature topography characterized by splendid examples of peak, cirque and valley glacial corrasion, leaving the surface excessively rugged. The post-glacial stage has been of short duration.

The local climate favors rapid destruction of land forms. Precipitation, largely in the form of snow, is unusually high, due to the rising of warm, moisture laden southwest winds in passing the high Cascades. This is accompanied by a high run-off, with the result that streams of mapable size and continuous flow are very numerous. The drainage pattern is dendritic and the land surface is maturely dissected by both streams and glaciers.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Vol. XXVII, pp. 215–243

Editor, Ralph W. Tower

OPERATING FEATURES OF THE AUDION

BY

E. H. Armstrong

NEW YORK
PUBLISHED BY THE ACADEMY
2 August, 1917

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[ANNALS N. Y. ACAD. SCI., Vol. XXVII, pp. 215-243. 2 August, 1917]

OPERATING FEATURES OF THE AUDION[1]

BY E. H. ARMSTRONG

CONTENTS

PART I

EXPLANATION OF THE ACTION OF THE AUDION AS AN AMPLIFIER AND AS A DETECTOR OF HIGH-FREQUENCY OSCILLATIONS

Although the audion has been in use for several years as an amplifier and a detector of high-frequency oscillations, the explanations advanced to account for its action do not appear to be satisfactory. With the idea of pointing out some features of operation which heretofore do not seem to have been appreciated, the following explanation and oscillograms are given.

The audion is essentially an electron relay; that is, the exhaustion is carried to such a point that the amount of gas present is exceedingly small, and the current between the hot and cold electrodes is entirely thermionic, the absence of gas making impossible the presence of positive ions. The operating characteristic of such a relay is shown in Fig. 1. This characteristic was obtained in the manner indicated in Fig. 2. The

[1] The material for the present article appeared in part in the *Electrical World* December 12, 1914, and in part in the *Proceedings of the Institute of Radio Engineers*, September, 1915. It has been combined, revised, and partly rewritten for the present publication.

potential of the grid with respect to the filament was varied in step between —10 and +10 volts, by means of the potentiometer *P*, corresponding readings of the grid voltage and wing current being taken in order to plot the curve of Fig. 1. The characteristic shows that, starting with the grid and filament at zero potential difference, a negative charge imparted to the grid produces a decrease in the wing current and a positive

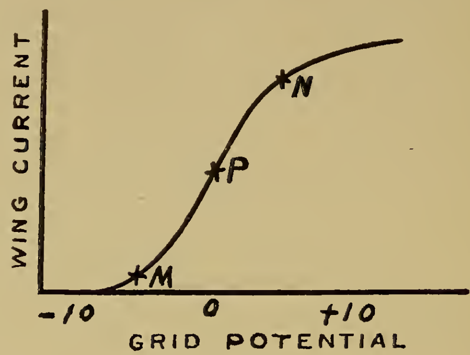

FIG. 1

charge imparted to the grid produces an increase in the wing current. This is the fundamental action of the audion when used either as an amplifier or a detector. The reason for this action will appear upon examination of the behavior of an audion of the type shown in Fig. 3.

The wings of the audion were placed symmetrically with respect to the

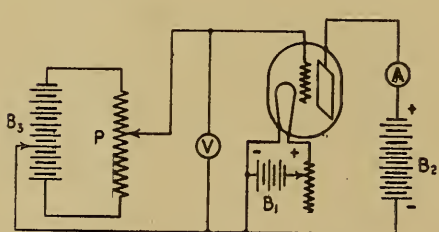

FIG. 2

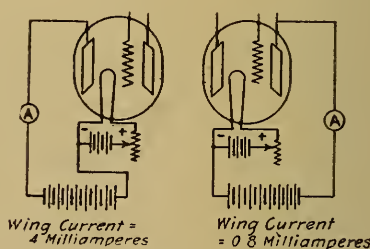

FIG. 3

filament, but only one grid was employed. It was found that, under similar conditions of filament temperature and voltage of the battery B_2, a considerably smaller current was obtained between the filament and plate on the side in which the grid was inserted. In both measurements the grid was left entirely free of any connection with the rest of the apparatus. Obviously the grid obstructed the flow of the thermionic current. Investigation showed that this was due to the charge accumulating on the grid when exposed to bombardment by the electrons passing from the filament to the wing. The electrons pass readily enough into the grid but cannot easily escape from it, and as a consequence of this, negative electricity piles up on the grid. The potential assumed by the grid

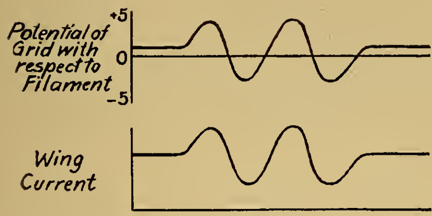

Fig. 4

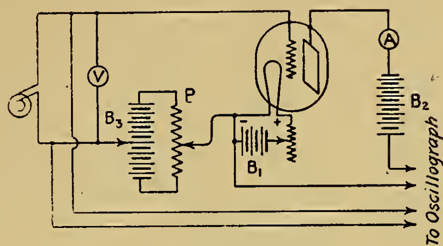

Fig. 5

when exposed to this bombardment may be several volts negative with respect to the negative terminal of the filament, it may be the same as the negative terminal, or it may be positive with respect to the negative terminal, but it will always be negative with respect to the potential of the field in the plane of the grid which would exist if the grid were removed from the bulb. The negative charge on the grid, therefore,

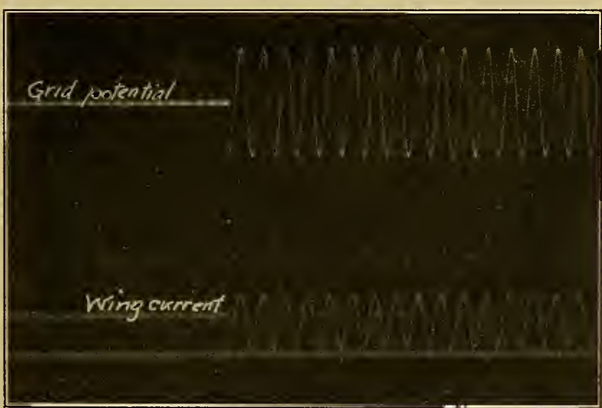

Fig. 6

impedes the flow of electrons from filament to plate, causing the decrease in the wing current. The placing of a positive charge on the grid from an external source tends to neutralize the negative charge on the grid, thereby permitting an increase in the wing current. The addition of a negative charge to the grid increases the deflection of the electrons and produces a further decrease in the wing current.

An alternating E. M. F. impressed between the grid and the filament causes variations in the wing current in the manner indicated in Fig. 4, the positive alternation producing an increase and the negative alternation a decrease in the wing current. This is the action involved in the audion when it is used as an amplifier.

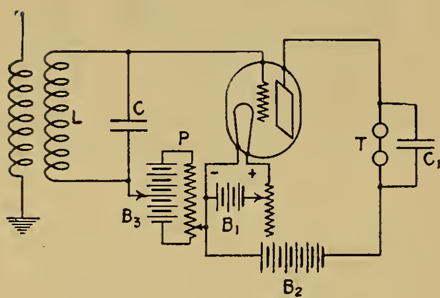

Fig. 7

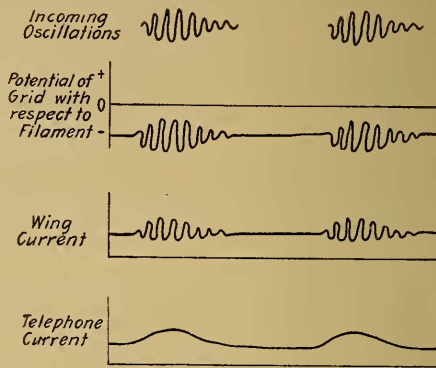

Fig. 8

To substantiate the above and other actions, the writer, working in conjunction with Prof. J. H. Morecroft, of Columbia University, has secured oscillograms which substantiate the idea just presented. Fig. 5 shows the arrangements with which the test was carried out.

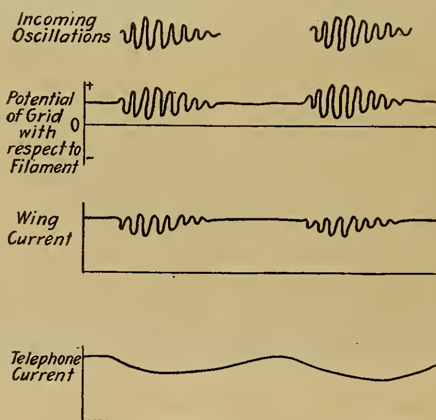

Fig. 9

The potentiometer P was used to adjust the grid to a potential corresponding to point P at the center of the operating part of the curve shown in Fig. 1. The audion is capable of handling the greatest amount of energy as an amplifier when the grid potential is adjusted to this point. Fig. 6 shows the oscillogram of the action as an amplifier. The result bears out the explanation already given.

The action of the audion as a detector of high-frequency oscillations is quite different from its action as an amplifier. Since the incoming

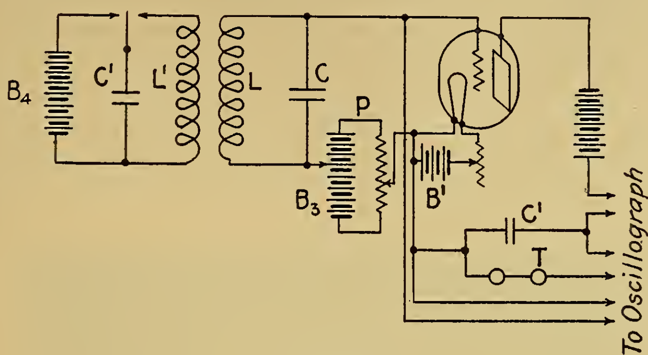

FIG. 10

oscillations are of too high a frequency to affect directly the telephone receiver, the audion must be so connected and adjusted that the cumulative effect of a group of oscillations in the grid circuit is translated into a single low-frequency pulse or variation in the telephone current. This may be done in two ways, one depending on the non-linear form of the

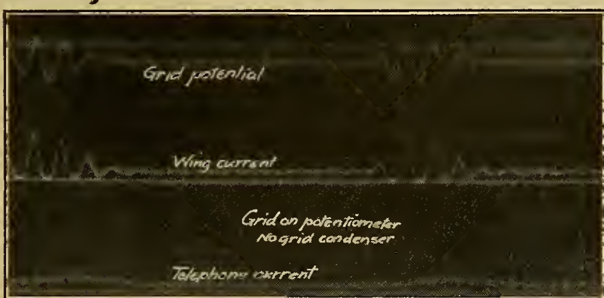

FIG. 11

operating characteristic of the audion and the other depending on the so-called "valve" action between hot and cold electrodes at low pressures.

Fig. 7 shows the connection used for operating in the first-named manner. The potentiometer P is employed for the purpose of adjusting the potential of the grid to point M on the characteristic curve of Fig. 1. The action is much the same as in one of Professor Fleming's methods of using his valve. A group of high-frequency oscillations impressed on the grid causes corresponding high-frequency variations in the continuous current in the wing current, but owing to the fixing of the grid potential at the lower bend of the curve by adjustment of the potentiometer in the grid circuit, the amplitude of the positive part of the high-frequency current in the wing circuit exceeds the amplitude of the negative part. As the positive half-waves are greater than the negative half-waves, more electricity flows in one direction than the other, and the condenser C_1, through which the high-frequency current in the wing circuit flows, becomes charged, the side connected to the battery B_2 having the positive charge. This charge accumulates in C_1 in a relatively short time, approximately that of the duration of a wave train. C_1 then discharges

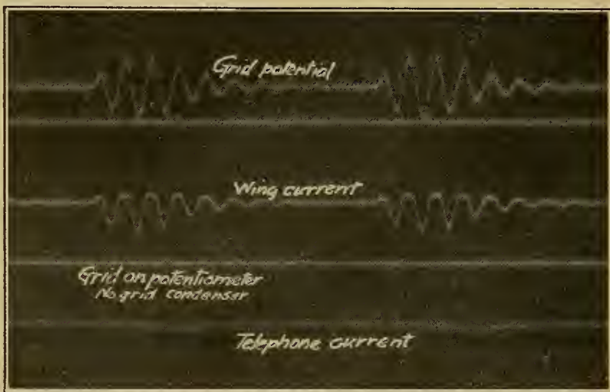

FIG. 12

through the telephone T, the rate of this discharge being determined by the constants of the telephones and the condenser. It is probable that this discharge is aperiodic or nearly so. In any case the main part of the discharge through the telephones is in the same direction as the current due to the battery B_2 and constitutes an increase in the current in the telephones. As this action is repeated for each group of oscillations, a series of wave trains causes what might be regarded (in its action on the telephones) as an alternating current in the telephones superposed on the continuous current and having a fundamental frequency equal to the number of wave trains per second. The action is shown diagrammatically in Fig. 8.

If the potential of the grid is adjusted to the upper bend in the curve of Fig. 1, as at point N, the fundamental action will be the same, but the effect of high-frequency oscillations in the grid circuit on the wing current will be reversed. The amplitude of the negative part of the high-frequency oscillations in the wing circuit will exceed the amplitude of the positive part and the condenser C_1 will become charged, but in the opposite sense, the side connected to the battery B_2 becoming negative. The discharge of the condenser through the telephones will therefore be in the opposite direction to the flow of the continuous current of the wing circuit, and will constitute a decrease in the telephone current. Diagrammatically the action is as indicated in Fig. 9.

Oscillograms bearing on these actions were obtained in the matter indicated in Fig. 10. Oscillations were set up by the discharge of the condenser C' through the inductance L', which was coupled with the in-

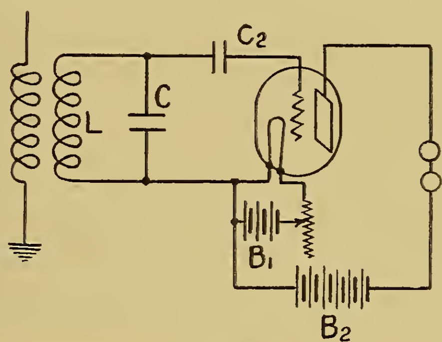

FIG. 13

ductance L of the tuned grid circuit. To permit the use of an ordinary General Electric oscillograph, an oscillation frequency of about fifty cycles per second and a group frequency of two or three cycles were employed. The action of the audion is the same, regardless of frequency, provided that the circuit constants are suitably modified to fit the frequency employed. In this case the oscillation frequency of the circuit $C'L'$ was fifty cycles and the circuit LC was accordingly tuned to the same frequency. The capacity of C_1 was selected to correspond to the low frequency employed. Figs. 11 and 12 show oscillograms taken as indicated in Fig. 10, with the grid potential adjusted respectively to the lower and the upper bends of the operating characteristic. It will be observed that the telephone current reaches in Fig. 11 its maximum value, and in Fig. 12 its minimum value, when the oscillating current has almost died away. This effect would be shown more plainly with a higher oscillation frequency, but even at the frequency used it is quite evident.

To make use of the "valve" action between hot and cold electrodes for the detection of high-frequency oscillations a connection as shown in Fig. 13 is used. In this case a condenser C_2 is inserted somewhere in the circuit between the grid and filament to prevent the flow of a continuous current between them, and the grid is therefore left free to assume a potential determined by its position with respect to the filament and wing. Usually this will be somewhere near the center of the operating part of the curve in Fig. 1; that is, near point P. Now the action for incoming oscillations, as far as the closed oscillating circuit, filament, grid and condenser C_2 are concerned, is identical with the rectifying action of the Fleming valve. An incoming wave train sets up oscilla-

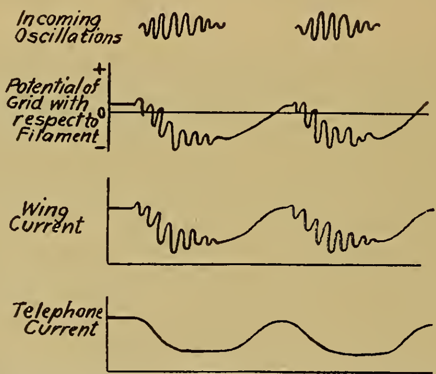

FIG. 14

tions in the closed circuit LC which are rectified by the "valve" action of the filament and grid, and the rectified current is used to charge the condenser C_2. Electrons pass readily enough into the grid, but cannot easily escape therefrom, and a negative charge is built up on the side of the condenser connected to the grid. The negative charge thus imparted to the grid cuts down the flow of electrons from the filament to the wing, producing a decrease in the wing and telephone currents. At the end of a wave train the charge in C_2 gradually leaks off and the wing current returns to its normal value. The charge and discharge of this condenser take place in the manner indicated in Fig. 14.

One group of oscillations produces a single low-frequency variation (decrease) in the telephone current and a series of wave trains produces a corresponding series of low-frequency variations in the telephone current. In Fig. 15 is shown an oscillogram of the behavior of the audion when the "valve" action is employed for the detection of oscillations.

With the means at hand it was impossible to obtain the variations of grid potential directly, as the leak introduced by connecting the oscillograph to the grid would destroy the cumulative action. The grid potential, however, varies in exactly the same manner as the wing current. The fundamental detecting action is, therefore, that of a valve, the high-frequency oscillations being rectified between the filament and the grid to charge the grid and the grid condenser. The charged grid then exerts a relay or trigger action on the wing current, so that the audion is at once a rectifier and an amplifier. A somewhat similar combination

FIG. 15

of rectifying and amplifying actions occurs in the arrangement shown in Fig. 7. The action of the audion is being further studied by Professor Morecroft and the writer in the Hartley Research Laboratory, Columbia University, and the results of these investigations will soon be published.

PART II

SOME RECENT DEVELOPMENTS OF THE AUDION RECEIVER [2]

It will be observed from the oscillogram of Fig. 15 that in addition to the regular detecting phenomena the audion is simultaneously acting as a repeater of the radio frequencies; so that oscillations of the grid circuit set up oscillations of similar character in the wing circuit of the audion. In the ordinary detector system no use is made of the repeating action,

[2] Paper read before the Institute of Radio Engineers, New York, March 3, 1915, and before the Boston Section, April 29, 1915.

and it is the purpose of the present paper to show that it may be turned to account to produce improvements in the reception of signals which completely overshadow any of the particular advantages of the audion when used as a simple detector. The ordinary detector circuit is illustrated by Fig. 13 and the phenomena present therein may be summed up diagrammatically by the curves of Fig. 14. It will be seen from these that the radio frequency oscillations present in the wing circuit of Fig. 13 with the ordinary audion are necessarily small, and also that they are of no value in producing a response in the telephones; but by providing means for increasing their amplitude and means for utilizing them to reënforce the oscillations in the grid circuit, it becomes possible to produce some very remarkable results.

Reënforcement of Radio Frequency Oscillations by the Audion

There are two ways of reënforcing the oscillations of the grid circuit by means of those in the wing circuit. The simplest way perhaps is to

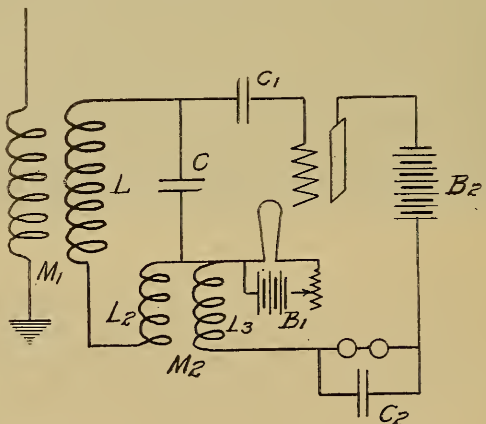

Fig. 16

couple the two circuits together in the manner shown in Fig. 16. This is essentially the same as Fig. 13, but modified by the introduction of the inductively coupled coils L_2 and L_3 in the grid and wing circuits respectively and by the condenser C_2, which forms a path of low impedance across the telephones for the radio frequencies. In such a system, incoming signals set up oscillations in the grid circuit which repeat into the wing current producing variations in the continuous current, the energy of which is supplied by the battery B_2. By means of the coupling M_2, some of this energy of the wing oscillations is transferred back to the grid circuit, and the amplitude of the grid oscillations thereby increased. The amplified grid oscillations then react on the wing circuit by means of the grid to produce larger variations in the wing current, thus still further reënforcing the oscillations of the system. Simultaneously with this procedure the regular detecting action goes on; the condenser C_1 is charged in the usual way, but accumulates a charge which is proportional, not to the original signal strength, but to the final amplitude of the oscillations in the grid circuit. The result is an increased response in the telephone proportional to the energy amplification of the original oscillations in the grid circuit. It will be observed from the operating characteristic (the relation between the grid potential and wing current) that the amplitude of the variation in the wing current is directly dependent on the variation of the grid potential. This indi-

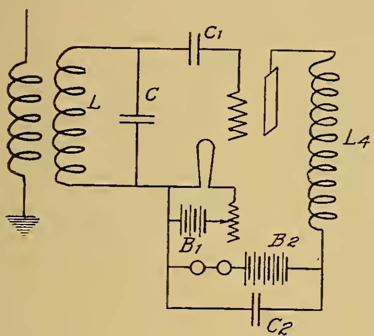

FIG. 17

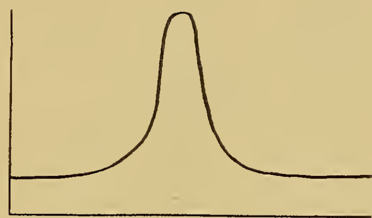

FIG. 18

cates that the grid circuit should be made up of large inductance and small capacity to obtain the maximum voltage which it is possible to impress on the grid. For moderate wave lengths the tuning condenser C of the grid circuit may be omitted altogether and the capacity of the audion alone used to tune the circuit. For long wave lengths the distributed capacity of the grid circuit inductance becomes so high with respect to the capacity of the audion that better results are obtained by the use of a tuning condenser to fix definitely the points of maximum potential difference across the grid and filament of the audion.

In the second method of reënforcing the oscillations of the grid circuit the wing circuit of the audion is tuned by means of an inductance introduced as shown by Fig. 17. This differs from the ordinary detector circuit of Fig. 13 by the addition of the coil L_4 and the condenser C_2. The manner in which the grid oscillations are amplified may best be understood by the following analysis. With no oscillations in the system, the potential difference between filament and wing will be approximately the voltage of the battery B_2, but when oscillations are set up in the grid circuit, causing radio frequency variations of the wing current, the potential of the wing with respect to the filament varies as the reactance voltage of the wing inductance alternately adds to and subtracts from the voltage of the battery. When a negative capacity charge is placed on the grid, the wing current will be reduced and the direction of the reactance voltage of the wing inductance will therefore be the same as the voltage of battery B_2. The reactance voltage will therefore add to the battery voltage, and the difference of potential between wing and filament and also between wing and grid will be increased. Similarly, when a positive charge is placed on the grid the wing current is increased and the reactance voltage of the wing inductance opposes the battery voltage, producing a decrease in the potential difference between grid and

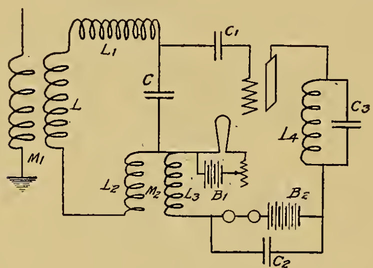

FIG. 19

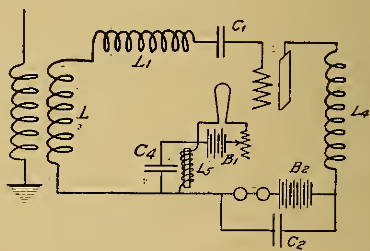

FIG. 20

wing. Hence, supposing a negative capacity charge is placed on the grid, the tendency of the corresponding increase in the potential of the wing with respect to the grid will be to draw more electrons out of the grid, thereby increasing the charge in the condenser formed by the wing and grid, the energy for supplying this charge being drawn from the wing inductance as the wing current decreases. The increased negative charge on the grid tends to produce a still further decrease in the wing current and a further discharge of energy from the wing inductance into the grid circuit. On the other hand, when a positive charge is placed on the grid, the potential difference between grid and wing is reduced and some of the energy stored in the capacity formed by them is given back to the wing inductance. During this part of the cycle, electrons are being drawn into the grid from the surrounding space to charge the grid condenser in accordance with the well known valve action, and this, in effect, is a conduction current, so that a withdrawal of energy from the circuit takes place. In spite of this withdrawal of energy, however, a well defined resonance phenomena between the audion capacity and the wing inductance is to be expected, and in the reception of signals such is found to be the case. When the wing inductance is properly adjusted at the resonance frequency, energy from the wing circuit is transferred freely to the grid circuit, and the oscillations build up therein and are rectified in the usual way.

A curve showing the general relation between the signal strength and value of wing inductance is shown in Fig. 18, the circuits used being those of Fig. 17. As the capacity of the audion is the main means of transferring energy from the wing to the grid circuit, best results are obtained when the condenser C is very small. On account of the very small capacity of the audion, the effectiveness of this method of tuning is more pronounced at the higher frequencies, but by the use of a shunt

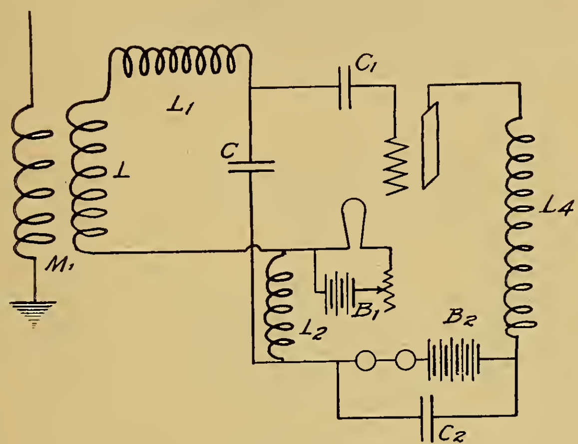

Fig. 21

condenser across the inductance of the wing circuit very good amplification is secured on frequencies as low as 30,000 cycles (10,000 meters wave length). The best results, however, are obtained with some combination of coupling and wing circuit tuning, as illustrated in Fig. 19. Other methods of coupling may be employed between the grid and wing circuits, electrostatic and direct magnetic couplings being illustrated in Figs. 20 and 21. The arrangement of Fig. 21 operates in the same way as the system with the two-coil coupling; but the electrostatic coupling of Fig. 20 works in an odd way. It is necessary, in this connection, to complete the wing circuit for the continuous current of the battery, and this is done by shunting the coupling condenser C_4 by a coil of high inductance. The continuous current of the wing circuit flows through this coil and C_4 provides a path of low impedance around this coil for the radio frequency oscillations of both the grid and wing circuits. When a positive charge is placed on the grid, an increase in the wing current results, the alternating component of the wing current charging the condenser C_4 and the sum of the currents passing through C_4 and L_4 equaling the current through the audion. When a negative charge is placed on the grid the current through the audion is reduced and the inductance L_5 discharged into the condenser shunted across it, charging it in the opposite way to that caused by the increase in the wing current. In both cases, C_4 then discharges through the grid circuit, reënforcing the oscillations therein.

Audio Frequency Amplification

It is possible to combine with any of these systems a system of audio frequency circuits which amplify the telephone current in exactly the

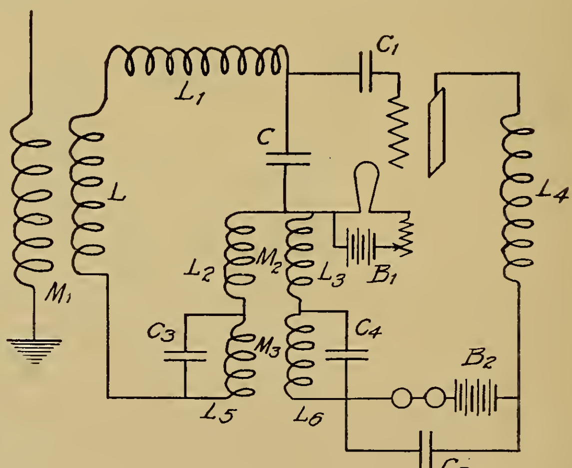

Fig. 22

same manner as the radio frequency oscillations are amplified, and such a system is shown in Fig. 22. Here M_2 represents the coupling of the radio frequencies, and the coils are of relatively small inductance. M_3 is the coupling for the audio frequencies, and the transformer is made up of coils having an inductance of the order of a henry or more. The condensers C_3 and C_4 having the double purpose of tuning M_3 to the audio frequency, and of by-passing the radio frequencies. The total amplification of weak signals by this combination is about 100 times, with the ordinary audion bulb. On stronger signals, the amplification becomes smaller as the limit of the audion's response is reached.

The Audion as a Generator and Beat Receiver

Any repeater, which is also an energy amplifier, may be used to produce continuous oscillations by transferring part of the energy in the circuit containing the battery back to the controlling circuit to keep the latter continuously excited. By providing a close enough coupling between the grid and wing circuits, sufficient energy is supplied to the grid circuit to keep it in continuous oscillation, and as a consequence thereof oscillations of similar frequency exist in all parts of the system. The

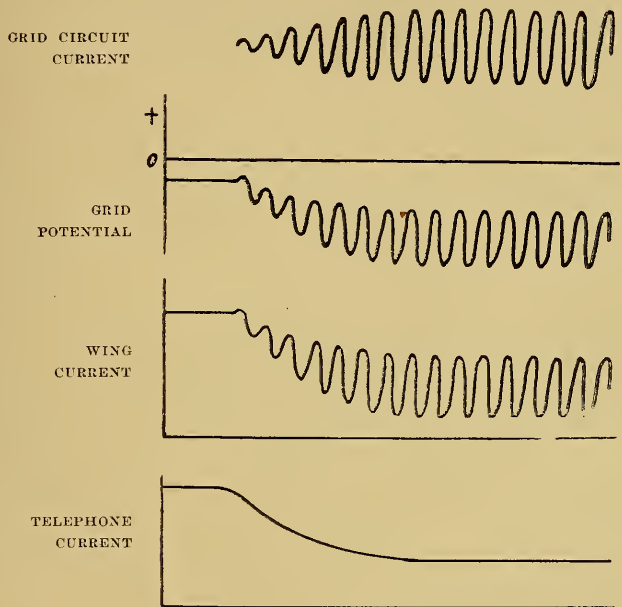

Fig. 23

frequency of these oscillations is approximately that of the closed grid circuit if the tuning condenser of that circuit is large with respect to the capacity of the audion. If this capacity is small, then the wing circuit will exert a greater influence on the frequency of the system, and it will not approach that of the grid circuit so closely. When such a system of circuits is in oscillation, it has been found possible not only to receive continuous waves by means of the beat method, but also very greatly to amplify them as well.

The phenomena involved may best be understood by reference to Figs. 23 and 24, which show the relation between wing current and time at the beginning of oscillation. When the audion begins generating, the grid oscillations are continuously rectified to charge the grid condenser, and this charge continuously leaks off either by way of the grid or by means of a special high resistance placed in shunt with the condenser. As the negative charge builds up in the grid condenser, it decreases the average value of the continuous current component of the wing current, and therefore limits the amplitude of the oscillations of the grid circuit until a point is finally reached where the rate at which electricity is supplied to the grid condenser is just equal to the rate at which it leaks off. Con-

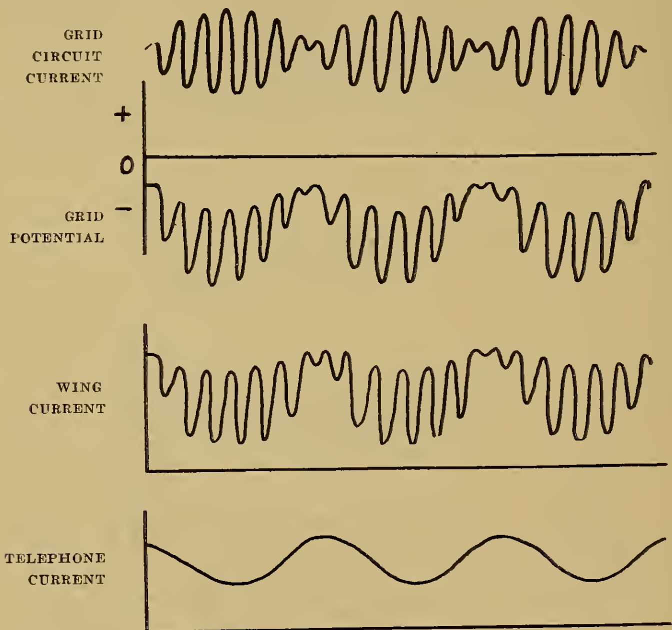

FIG. 24

sider now the effect on the system of an incoming continuous wave having a frequency slightly different from the frequency of the local oscillations. The presence of the local oscillations will not in any way interfere with the amplifying powers of the system, and the incoming oscillations will build up in exactly the same manner as for the non-oscillating state, but to a greater degree, because of the closer grid and wing coupling. Simultaneously with the amplifying of the incoming wave, beats are produced between the local and the signaling currents, the effect being alternately to increase and decrease the amplitude of the oscillations in the system. From Fig. 23 it will be apparent that when this steady state is reached an increase in the amplitude of the grid oscillations by any means whatever will increase the negative charge in the grid condenser, producing a decrease in the average value of the wing current, and hence a decrease in the telephone current. On the other hand, a decrease in the amplitude of the oscillations will allow some of the negative charge in the grid condenser to leak off and thereby permit an increase in the telephone current. Hence, when incoming and local oscillations add up, the negative charge in the grid condenser is increased and a decrease in the telephone current results. When the two frequencies are opposed, some of the charge in the grid condenser leaks off and an increase in the telephone current occurs. The result is the production in the telephones of an alternating current having a frequency equal to the difference in the frequencies of the local and incoming oscillations and having the very important property of being almost simple harmonic. Fig. 24 illustrates the characteristics of this method of reception. The complete phenomena may be summed up as follows. Incoming oscillations are simultaneously amplified and combined in the system to produce beats with a local oscillation continuously maintained by the audion. The radio frequency beats are then rectified by the audion to charge the grid and the grid condenser, and this charge varies the electron current to produce an amplifying action on the current in the telephones.

When the grid condenser is omitted, the beat phenomenon is slightly modified, and the audio frequency variation of the telephone current is produced according to the asymmetric action outlined in a previous publication dealing with the operating features of the audion. The system is more sensitive with the grid condenser, but the same general result is obtained by either method of reception.

Peculiar Features of Oscillation

Some very interesting features of operation accompany the production of oscillations in the system. Suppose the audion is not oscillating, and the grid and wing coupling is fairly weak. As this coupling is increased, the point at which oscillations begin is indicated by a faint click in the telephones accompanied by a slight change in the character of the static. The oscillations produced are usually so high in frequency and constant in amplitude that they are entirely inaudible. As the coupling is still further increased, a rough note is heard in the telephones, the pitch decreasing with increase of coupling. This note is produced by the breaking up of the oscillations into groups, and it occurs whenever electricity is supplied to the grid condenser at a greater rate than that at which it can leak off. The result is that the grid is periodically charged to a negative potential sufficient to cut off entirely the wing current, causing a stoppage of the local oscillations until the grid charge leaks off and the wing current reëstablishes itself. The frequency of this interruption depends largely on the capacity of the grid condenser, the resistance of its leakage path, and the amplitude of the local oscillations; it may be varied from several hundred down to one or less per second. This effect is sometimes troublesome in the reception of signals, especially with high vacuum tubes. It may be eliminated, however, by increasing the leak of the grid condenser by means of a high resistance shunt. The best coupling for receiving continuous waves lies somewhere between the point at which oscillations start and the point at which interruption begins, and

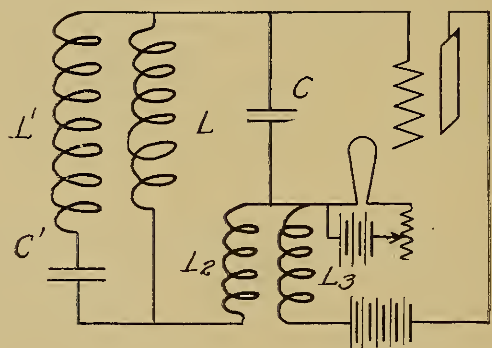

FIG. 25

can only be determined by trial. In this region, trouble is sometimes experienced by the appearance of a smooth musical note in the telephone. This occurs under certain critical conditions of coupling with the antenna when the grid circuit oscillates with two degrees of freedom. Two slightly different frequencies are therefore set up, producing beats which are rectified by the audion in the usual way. This effect is quite critical, and when it causes interference with signals, a slight readjustment of the circuit will usually make it disappear. It may, however, be made perfectly steady and reproduced at will by the system shown in Fig. 25, where two grid circuits of different periods are provided. Two frequencies are therefore generated, one having the frequency of the circuit LCL_2, and the other the frequency of the circuit $L'C'L_2C$. This arrangement may replace to advantage the ordinary buzzer for producing groups of oscillations. *The foregoing explanations refer to the audion only* *when it is used as an electron relay.*[3] *When there is an appreciable amount of gas in the tube in the ionized state, disturbances of an entirely different character occur.*

AUDIO FREQUENCY TUNING

One of the very important advantages of the receiver when used for continuous waves is that the alternating current produced in the telephones is almost a pure sine wave. Only when the audio frequency is simple harmonic can selectivity be obtained by tuning the telephone circuit. A distorted wave such as that produced by spark signals possesses many harmonics, and as each may be picked out by the tuned telephone circuit there is little chance of separating two spark signals by audio

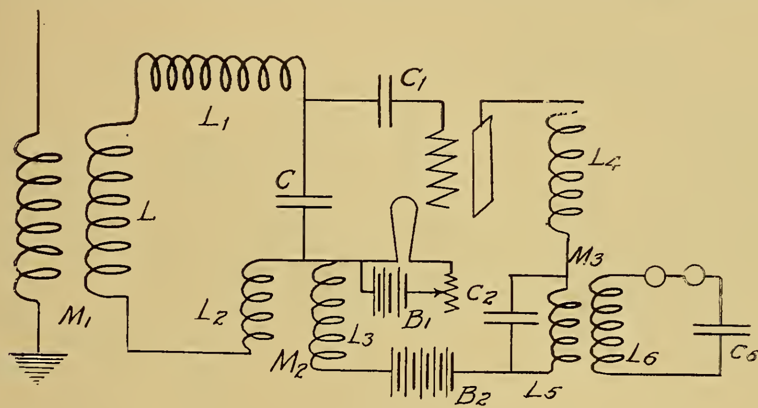

FIG. 26

frequency tuning. With continuous waves, however, the pure wave produced by the beat method of reception makes it possible to obtain selectivity by the audio frequency tuning, resonance being fully as sharp as in radio frequency circuits. Two methods of audio frequency tuning are shown in Figs. 26 and 27. In Fig. 26, the telephone is inductively connected to the wing circuit of the audion by means of a transformer; the secondary of which includes besides the telephone a tuning condenser. In this connection, the telephone, with a resistance of many thousand ohms, is placed directly in the tuned audio frequency circuit, and hence

[3] *Electrical World*, December 12, 1914; and also discussion in *London Electrician*, between Reisz and de Forest on the difference between electron and gas relays. (February 6, 1914, page 726; March 13, 1914, page 956; June 12, 1914, page 402; July 3, 1914, page 538; July 31, 1914, page 702.)

for good tuning the inductance of the coil L_6 must be made extremely large to secure the necessary ratio of the reactance of L_6 to the resistance of the circuit. This disadvantage is overcome in the system of Fig. 27 by removing the telephones from the audio frequency circuit, and using the latter to operate a second audion. The telephones may then be placed in the wing circuit of this audion without adding appreciably to the damping of the circuit. The tuning of the circuit L_6C_6 may therefore be made very sharp with reasonable values of inductance simply by keeping the resistance low. In this case considerable amplification is obtained by the use of resonance in the transformer M_3 to increase the voltage impressed on the grid of the second audion. The great advantage of this kind of tuning is shown by the following example. Suppose

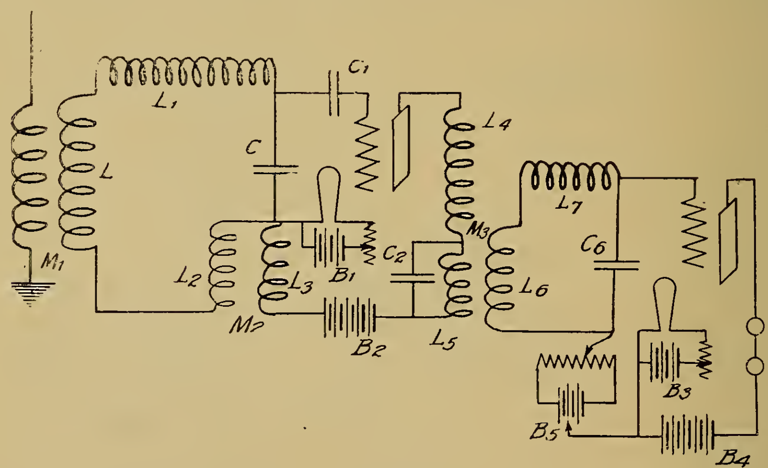

Fig. 27

the incoming signal has a frequency of 50,000 cycles, and the local frequency is 49,000 cycles. The differential frequency is 1,000, and the audio frequency circuit is tuned accordingly. An interfering wave 1 per cent shorter than the signaling wave, of 49,500 cycles, will produce an audio frequency of 500 cycles per second, which will not appear at all in the wing circuit of the second audion unless it is many times stronger than the 1,000 cycle signal. This combination of radio and audio frequency tuning is too selective for use at the present time, even when the sending station is equipped with an alternator, as the slight changes in frequency of the radiated wave produce changes in the beat frequency of the receiver which carry it out of range for the sharply tuned audio frequency circuit. A disadvantage of this method of tuning is that atmospheric disturbances produce a musical note due to shock excitation of the audio frequency system. Very loose coupling with the wing circuit of the first audion is a partial remedy for this. There are times, however, when interference is more troublesome than static, and in such cases the method may be used to great advantages. If desired, both radio and audio frequency tuning can be carried out in the same audion as indicated in Fig. 22. This combination is apt to be somewhat troublesome to operate as a cumulative amplification is obtained in the audio frequency as well as in the radio frequency system.

Cascade Systems

Where a greater amplification than can be obtained with one audion is required, cascade working of the radio frequency systems may be resorted to by coupling together two or more audion systems, each connected as already described, in the manner indicated in Fig. 28. The

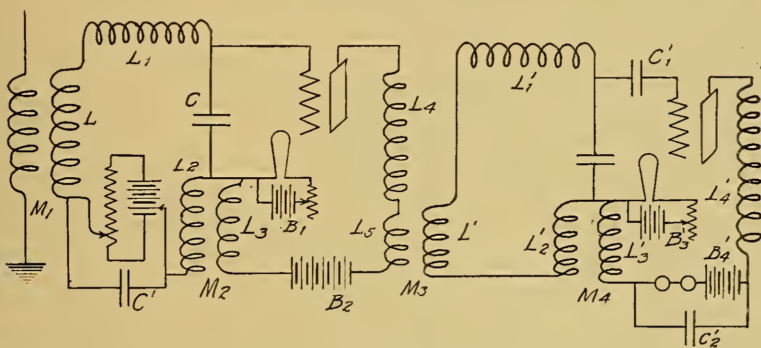

Fig. 28

incoming oscillations in the first audion system are amplified in the usual manner and set up oscillations in the second system by means of the coupling M_3. The oscillations initially set up in the second system are again amplified, and then rectified in the second audion to produce audible response in the telephones. For the reception of spark signals, considerable adjustment is required to get the best results without causing one or the other, or both, of the systems to generate oscillations. It will be found that after the first circuit is adjusted to the point of oscillation and the second is coupled with it, the strength of signal in the first system will be reduced owing to the withdrawal of energy from it by the second system. The signals may then be again brought up in strength by increasing the coupling between the grid and wing circuits of the first audion until the appearance of the local oscillations indicates that the limit of amplification has been reached. By careful adjustment about a thousand times amplification and very sharp tuning can be obtained with two steps.

For continuous wave reception, there are several methods of operating cascade systems. It is possible to have either system generate oscillations, the other system acting simply as an amplifier or both systems may be made to generate in synchronism. It will generally be found that when both systems produce oscillations, beats will be produced, so that a continuous note is heard in the telephones; but by adjusting the frequency of one of the systems the pitch of this note will be reduced as the two systems approach synchronism, until finally at one or two hundred

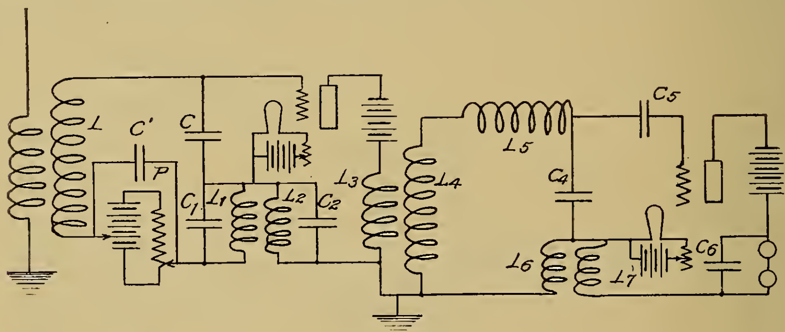

FIG. 29

beats per second the two systems pull into step in much the same way as two alternators. The ability of the two systems to keep in step depends mainly on the value of the coupling between them, and the closer this is the better the two hold together. There is still another way of working this combination, and that is asynchronously. In this case beats are continuously produced in the system so that a continuous note is heard in the telephone, but the circuits may be so adjusted that the note is not loud enough to be troublesome, or it may be tuned out of the telephone in the manner previously described. Incoming oscillations are combined in the system to produce beats with the beats already present, so that a rather curious note is heard. Very good amplification is secured by this method, though naturally the system is troublesome to operate.

It may be noted here that whenever a signal is too weak to read with one audion system, and cascade operation becomes necessary, it is always better practice to use the cascade circuits for the radio frequencies, even if the regenerative circuits are not employed with each individual audion system. The frequency of the oscillations set up in the circuits by static are, under normal conditions, the same as those of the incoming signal, and the static is therefore never amplified more than the signal. Usually it is amplified to a somewhat lesser extent, especially if regenerative circuits are employed. In the cascade system used for audio frequencies, a different condition exists. It is ordinary practice to connect the different stages by means of transformers, and this leads to conditions which cause the system to produce greater amplifications of the higher frequencies. The rate of change of the wing current of the detecting audion produced by static corresponds to a very high frequency, and as such is invariably amplified to a greater extent than the signal.

There is a second method of receiving continuous oscillations which

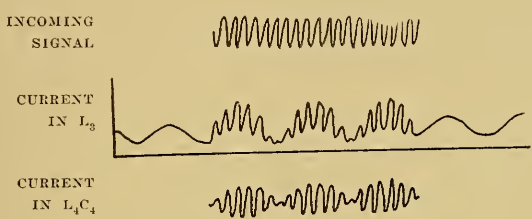

FIG. 30

makes use of the generating feature of the audion, but does not employ the beat phenomena. The amplifying ratio of the audion depends more or less directly on the value of the wing current, and by varying this current periodically there will be a corresponding periodic change in the amplifying power of the audion. Hence an audion arranged to repeat a continuous wave under such conditions will produce in its wing circuit oscillations which vary periodically in amplitude, and which may therefore be received by a simple audion system. The first audion may be arranged to produce the necessary variation in its amplifying power in the manner indicated in Fig. 29, which also shows the complete circuit for carrying out this method of reception. Here $C_1L_1L_2C_2$ is an audio frequency system designed to produce audio-frequency oscillations; and P is a potentiometer for adjusting the potential of the grid so that on the negative part of the oscillation in the circuit, the wing current is reduced practically to zero. The radio frequency circuit $C'LCC_1$ is tuned to the oscillation frequency of the incoming wave. The radio frequency oscillations cannot be detected in the first audion system, as the strong audio frequency current circulating in this system would produce a continuous note in the telephone receivers of such strength as to render inaudible all save very strong signals. By arranging to detect the oscillations in a second audion system coupled to the wing circuit of the first, interference of this sort is avoided, as the circuit L_4C_4 has a very high impedance for the audio frequency currents and the effect produced through the magnetic coupling of L_3 and L_4 on the second system is negligible. The capacity current between these two coils through the telephones to ground is, however, appreciable; and to avoid this it is advisable to ground their two adjacent ends as shown. The action of the system may be summed up as follows. The first audion system varies the amplitude of the incoming radio frequency oscillations at an audio frequency, and the second audion system amplifies and detects the radio frequency oscillations supplied to it by the first system. Diagrammatically, the phenomena occurring are as illustrated in Fig. 30. The system gives about the same response as can be obtained with a single audion working with the beat method of reception. The advantages derived from the heterodyne method of amplification and the dependence of the audio frequency note in the receivers on the wave length are, of course, lacking; but for the reception of waves having a frequency higher than that at which beat reception is practicable, this method is of value.

Effects of Atmospheric Disturbances

A very interesting feature of these receiving systems is their behavior under conditions of severe atmospheric disturbances, particularly when used for receiving continuous waves. Their success under such conditions is due to the fact that they combine, in addition to their inherent property of responding more readily to a sustained wave than a strongly damped one, the characteristics of the two most effective static eliminators known, the balanced valve and the heterodyne receiver. The function of the balanced valve is a physiological one, as it simply provides a means to shield the ear from the loud crashes which temporarily impair its sensitiveness for the relatively weak signals. In effect, it puts a limit on the noise which can be produced in the telephone by a stray, regardless of its amplitude. Now the effect of the static on an audion is to build up a negative charge on the grid, reducing the wing current, and the limit of the response which can be produced in the telephones is reached when the wing current is reduced to zero. Under ordinary conditions, this limit is too great to do much good; but when the audion is generating, it is possible by proper adjustment of the amplitude of the local oscillations to reduce the wing current to a point just above the lower bend in the operating characteristic so that the audion is rendered insensitive to a further increase in the negative charge on the grid. The strays which cause serious interference are of a much greater amplitude than the local frequency, so that no appreciable interaction between the two takes place, and the wing current is invariably decreased. Since the decrease in the wing current is not in proportion to the change in the grid potential, the response in the telephone and the effect on the ear of the operator are correspondingly reduced. Static of smaller amplitude than the local oscillations may interact with them to produce either an increase or a decrease in amplitude of the oscillation in the grid circuit, and may therefore cause either a decrease or an increase in the wing current. The wing current can, of course, increase to a relatively large value, but as it is impossible for the wing current to increase faster than the charge in the grid condenser can leak off, the rate of increase is necessarily slow. The response in the telephones is therefore not so disturbing as would be caused by a decrease of similar value where the rate of change of current is usually large.

When the system is operated without an auxiliary leak around the grid condenser, a peculiar paralysis of the audion is frequently caused by heavy static, no sound of any kind being heard in the telephone for a considerable length of time. If the apparatus is not touched, the paralysis may last for many minutes, and then suddenly disappear and the former sensitiveness be restored. The effect is primarily caused by the charging of the grid condenser to a sufficient potential to cut off entirely the flow of electrons to the wing, thereby decreasing the wing current to zero. Now, the way in which the negative charge in the grid condenser leaks off is chiefly by means of the positive ions in the tube, which are drawn into contact with the grid when it becomes negatively charged. These positive ions are the result of ionization by impact, and when the voltage of the wing battery is properly adjusted, they can be produced only in the region between the grid and the wing, since the velocity attained by the electrons between the filament and grid is very low. When the grid is charged to a high negative potential it keeps all the electrons between the grid and filament, thereby barring them from the region between grid and wing. Hence the production of positive ions must cease, and the usual means of removing the negative charge from the grid vanishes. The resistance of the leakage path of the grid condenser must then be almost infinite, as is shown by the very long time taken for the charge to leak from a condenser of approximately 0.0001 microfarads capacity. The effect is naturally the more pronounced the higher the vacuum, as the number of positive ions present is correspondingly reduced. A resistance of several hundred thousand ohms placed across the grid condenser gives a leak which is independent of the value of the wing current and which effectually prevents trouble of this kind. With the very high vacua now obtainable by the use of a molecular pump, there are practically no positive ions present, so that the auxiliary leak is always necessary. Under these conditions, it not only prevents paralysis by the static, but it also removes from the grid condenser the excess of negative electricity which accumulates in it, thereby increasing the sensitiveness of the audion and the sharpness of the signals in the telephones. The very high potentials to which the grid condenser may be charged by the static are surprising. These potentials may be measured in a very simple and accurate way, here described. After a stray has cut off the wing current, if we continuously increase the capacity of the grid condenser, the potential across it and hence the potential of the grid with respect to the filament will be decreased inversely as the capacity. A point will finally be reached where the grid potential is sufficiently reduced to allow the wing current to flow. When this occurs it indicates that the potential of the grid condenser is slightly less than that shown by the operating characteristic as necessary to reduce the wing current to zero. The potential to which the grid condenser was originally charged is equal to this voltage times the ratio of the capacity of the condenser at which the wing current began to flow to the original capacity. Voltages of over a hundred are not uncommonly reached by the grid and as one volt represents a very strong signal, the difficulties of the static problem are very forcibly presented.

The fact that static of large amplitude produces almost invariably a decrease in the wing current, while a signal (with beat reception) produces alternately an increase and decrease in the wing current, is a circumstance of which it should be possible to take advantage. The circuits can be arranged to rectify the wing current in such a way that only the increases in this current are available to produce a response in the telephones, but in carrying this method out, trouble is experienced from a shifting zero. A better way of making use of the difference in response is the following one. Suppose that we arrange two complete receiving systems oscillating in step with each other, but so related to the antenna that the beat currents in the two systems are 180 degrees apart. The result of this will be that at the instant when the incoming signal is producing an increase of current through the telephones in one receiver, it will be producing a decrease of current through the telephones of the other receiver; so that the two telephone currents are 180 degrees out of phase. Static of large amplitude does not interact with the local frequencies, and will produce simultaneously in each receiver a decrease in the telephone current. These two currents are therefore in phase with each other. On replacing each telephone by the primary of a transformer, and connecting their secondaries through a telephone in the proper phase, it is possible to balance out the static and at the same time secure an additive response of the signals from each receiver.

An arrangement of circuits by means of which this method can be carried out is shown in Fig. 31. Here two oscillating receiving systems

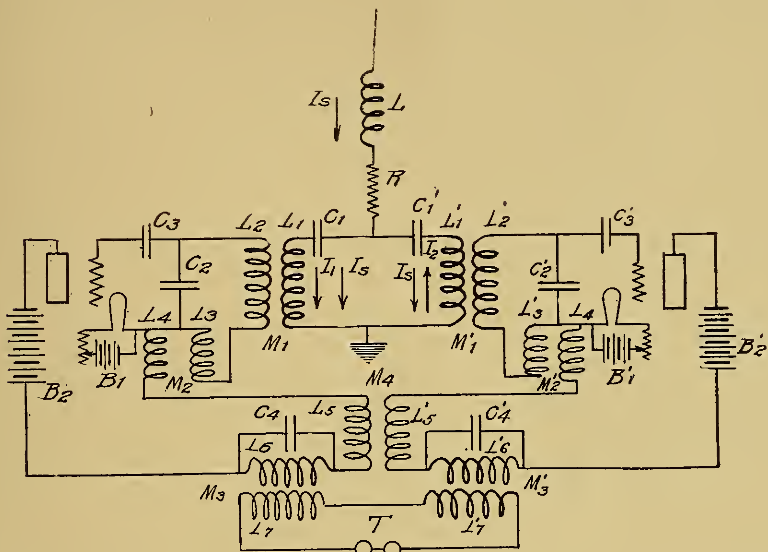

FIG. 31

are kept in step by means of the circuits $L_1C_1C_1'L_1'$. L_1C_1 and $L_1'C_1'$ are identical, and each is tuned separately to the frequency to be received. When both audions are oscillating in step, the flow of current in these circuits, as indicated by the vectors of Fig. 31, will be alternately up on one side and down on the other. The point between the condenser C_1 and C_1' will be a node; and the antenna may be connected to this point without disturbing the conditions appreciably if a resistance R, placed as indicated, is included in the antenna. This resistance need not be large enough to interfere seriously with the signal strength; it need only be large with respect to the resistance of the circuit $L_1C_1C_1'L_1'$, which circuit has a very low resistance.

Incoming oscillations pass through the divided circuit as indicated in the diagram, and therefore are in phase with the local oscillations of one receiver and 180 degrees out of phase with the local oscillations of the other. This produces the desired result in the currents through the transformers of the circuit T, which act in the manner already described.

It is found in practice that the oscillations set up in each system by the incoming signals tend to neutralize each other through the circuit $L_1C_1C_1'L_1'$. This effect is avoided by introducing in the wing circuits a differential coupling arranged to neutralize the coupling between the two grid circuits. It is possible to do this, as it does not affect the coupling of either receiver with the antenna, and does not interfere with the local operation until the effective coupling between the two systems is reduced to a point below which they will no longer remain in step. There are other ways of securing the same result, but the system shown will illustrate the general procedure in carrying out this method of balancing.

The practical results obtainable with these receivers may perhaps be of interest. At the present time, signals from all high-power stations from Eilvese (Germany) to Honolulu are heard day and night at Columbia University with a single audion receiver. Cascade systems give correspondingly better results, two stages being sufficient to make the night signals of Honolulu audible throughout the operating room. Interference with the signals from Nauen by the arc station at Newcastle, New Brunswick (Canada), is very easily eliminated by means of an audio frequency tuning circuit; and this is the most severe interference we have yet experienced, the two frequencies sometimes differing by less than 1 per cent and the arc signals being much the stronger.

These receivers have been developed in the Hartley Research Laboratory, Columbia University, and are mainly the result of a proper understanding and interpretation of the key to the action of the audion—the grid potential-wing current curve. In conclusion, I want to point out that none of the methods of producing amplification or oscillation depend on a critical gas action; they depend solely on the relay action of the tube employed (electron or gas relay) and the proper arrangement of its controlling circuits.

SUMMARY

The action of the audion as a detector and simple amplifier is explained, with the method of verification of the theory by means of oscillograms. To reënforce the oscillations in the grid circuit two methods are employed. First, to couple the grid circuit to the wing circuit and arrange the latter to permit radio frequency currents to pass freely in

it; and, second, to use a large inductance in the wing circuit, thereby tuning it to the incoming frequency (in conjunction with the capacity between the filament and wing in the audion itself). Both methods may be used together. Various methods of coupling grid and wing circuits are shown. Methods of combined audio and radio frequency amplification are described.

The audion, being a generator of alternating current of any desired frequency, can be used as a beat receiver. A steady audion generator of regular groups of radio frequency oscillations is illustrated. Various methods of audio frequency tuning permitting high selectivity are possible. By the use of two audions in cascade, amplifications as high as 1,000 are attainable. The cascade systems can be arranged so as to operate both audions either synchronously or non-synchronously.

As an alternative to beat reception of sustained wave signals, an arrangement is explained, wherein the amplifying ratio of a repeating audion is varied periodically at an audio frequency. Coupled to this system is a simple audion detector. Musical signals of any desired pitch are thus obtained.

It is found that static of large amplitude nearly always decreases the wing current, while a signal (with beat reception) alternately increases and decreases it. A system of circuits is described whereby this fact is taken advantage of in balancing out static while retaining the additive response to signals, thus effecting an elimination of static to a considerable extent.

Finally, instances of long-distance stations received and interference overcome in practice are given.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXVII, pp. 245-336

Editor, Ralph W. Tower

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OF THE

NEW YORK ACADEMY OF SCIENCES

WITH INDEX TO VOLUME XXVII

NEW YORK
PUBLISHED BY THE ACADEMY
30 November, 1917

THE NEW YORK ACADEMY OF SCIENCES

(LYCEUM OF NATURAL HISTORY, 1817–1876)

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SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

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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. XXVII, pp. 245–336. 30 November, 1917]

RECORDS OF MEETINGS

OF THE

NEW YORK ACADEMY OF SCIENCES

January to December, 1916

By RALPH W. TOWER, *Recording Secretary*

BUSINESS MEETING

3 JANUARY, 1916

The Academy met at 8:15 P. M. at the American Museum of Natural History, Vice-President Douglas W. Johnson presiding.

The minutes of the last meeting were read and approved.

The following candidate for active membership in the Academy, recommended by the Council, was duly elected:

Leo Wallerstein, 171 Madison Avenue.

The Secretary reported the following death:

Sir Henry Enfield Roscoe, Honorary Member since 1887, died 18 December, 1915.

The Academy then adjourned.

HENRY E. CRAMPTON,
Acting Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

3 JANUARY, 1916

Section met at 8:20 P. M., Vice-President Douglas W. Johnson presiding.

The following program was presented:

Douglas W. Johnson, The Strategic Value of Landforms in the Great Russian Retreat.

A. W. Grabau, Some Parallelisms in the Geology of Western Europe and America.

Summary of Papers

Dr. **Johnson** described and illustrated by specially prepared maps how the detailed movements in the Russian retreats of 1915 were influenced to a remarkable degree by the surface features of the country over which the contending armies moved.

Professor **Grabau,** with the aid of charts and lantern slides, contrasted the topographic, sedimentary and faunal relations of the British Isles and western Europe, particularly the Baltic region during the Tremadoc, Areing and Landeillo stages with the Potsdam, Beckmantown and St. Peters stages in the United States and southeastern Canada. Special reference was made, on the one hand, to the Caledonian and American lands and on the other to the Ceratopyge, Phyllograptus and Tetragraptus faunas of the Areing beds and to the trilobites, *Megelapsis limbata* and *M. plantilimbata* of the Landeillo beds. In the Baltic region the Dictyonema fauna thins outward to the east and is superseded by the Ceratopyge forficula forms. The possible routes of migration of marine forms at these stages in our geologic history between Europe and America was explained.

The Section then adjourned.

Chester A. Reeds,
Secretary.

SECTION OF BIOLOGY

10 January, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

Henry Fairfield Osborn, Dinosaurs which Mimic the Ostriches and other Struthious Birds.

Roy C. Andrews, The Sei Whale (*Balænoptera borealis*). Its History, Habits, External Anatomy, Osteology and Relationship. (Read by Title.)

H. von W. Schulte, On the Anatomy of a fœtal *Balænoptera borealis.*

John D. Kernan, Jr., Remarks on the Ear of *Balænoptera borealis.*

Summary of Papers

Professor **Osborn** described and illustrated the remarkably complete skeleton of a bird-like dinosaur allied to *Ornithomimus,* recently mounted in the American Museum. He showed its general resemblance to struthious birds in the form of the skull and hind limbs and discussed the various hypotheses which had been advanced concerning the life habits of this animal. He then contrasted it with *Tyrannosaurus,* a giant carnivorous dinosaur, and showed the wide adaptive divergence between these two branches of the carnivorous dinosaur stock. The paper was discussed by Dr. Gregory.

Professor **Schulte** stated that the following results are based upon the dissection of a fœtus measuring 37.5 cm. in length, collected by Mr. Roy C. Andrews at Rikusen, Japan. The complete details of the examination will appear in the Monograph of the Pacific Cetacea, to be published by the American Museum of Natural History.

The panniculus carnosus formed a very complete investment of the venter and sides throughout the region corresponding to the body cavities and neck. Over the dorsal muscles and pedicle it was replaced by aponeurosis. From this arrangement it was thought that it might serve by its contraction to maintain pressure upon the contents of the thorax and abdomen as the animal rose to the surface. It may further subserve an expirator function. In its disposition it closely resembles the cutaneous muscle of *Phocaena* except that in front of the shoulder its dorsal division overlies the ventral instead of forming with it a continuous sheet, which may, however, show a tendinous inscription.

Throat furrows were not yet present. The integuments of the intermandibular region, throat and thorax, well down upon the abdomen, were, however, redundant and rendered easily movable upon the deeper parts by the interposition of a layer of very loose areolar tissue. Between this and the skin was a complex muscle intimately bound to the integuments. From without inward was a thin layer of scattered fasciles of the dorsal panniculus, then the ventral panniculus, then mylohyoid, and finally a longitudinal stratum of hypoglossal cervical innervation, extending from mandibles to abdomen. The throat furrows, to which this redundency of the integumentary complex is plainly antecedent, have been explained as a provision for enlarging the capacity of the mouth (Kükenthal); but their presence on the thorax can hardly be so accounted for. Andrews has suggested that they may be a provision for great expansion of the thorax, taken in connection with the fact that in *Balœnoptera* the sternum is greatly reduced, is joined by only the first pair of ribs and costo-central articulations are present only from the second to the fourth or fifth rib. Dr. J. Vaughan has suggested that this extreme expansion of the thorax may be passive and would seem to be called for if it can be assumed that the diaphragm relaxes during the period of apnoea, when the animal is submerged.

The heart was practically unrotated, its long axis nearly dorso-ventral and not appreciably deviated to the left. Its chief internal peculiarity was the form of the valve of the fossa ovalis, like a perforated thimble attached all around to its base. There was, further, no Eustachian and no Thebesian valve. These conditions have been previously described by Knox and by Turner.

The trachea was wide, short and covered as far as its bifurcation by a thick walled muscular laryngeal sac. The structure of this is such as to preclude the possibility of its acting as a reservoir. It may possibly serve by its contraction to set up a current in the air within the capacious bronchial tree, so aiding in the diffusion and utilization of the contained air.

The liver was massive and of simple contours; the stomach showed four compartments; the intestine had undergone rotation and an ascending colon, splenic flexure and descending colon—in a word, the left colic loop of Bardeen was present and fixed; the cæcum was of moderate size, bluntly rounded at the apex. The chief peculiarity of the situs viscerum was the collacation of almost all of the intestine together with liver, spleen, pancreas and stomach in the preumbilical portion of the abdomen. There was no foramen epiploicum, a condition recorded by Hunter of certain whales.

The genito-urinary tract resembles closely the description of Daudt except that there is certainly no mesentery for the kidneys, nor was it evident that there was any real asymmetry of the internal or the external organs—the individual being a female—other than could properly be ascribed to the curvature of the fœtus.

The skull was remarkable for its rounded cranium, wide exposure of the supra-occipital, enormous auditory bullæ, straight axis and small development of rostrum, orbital process and squamosal.

There were thirteen pairs of ribs. The first rib was two headed on both sides. The ventral bar of the transverse process of the 7th cervical vertebra was lacking, that of the sixth was retarded in development and moveable upon the centrum. The pelvis showed no sign of an acetabulum. There was no trace of a femur.

The nasal fossa, larynx and ear were studied by Dr. John D. Kernan, Jr., of Columbia University, whom I have asked to present his results as a continuation of this communication.

Dr. **Kernan** stated that the important thing to note in connection with the ear of this animal is that it is of high mammalia type made over for life in the water. The external ear has disappeared, and neither muscle nor cartilages were observed in this fœtus, although both have been recorded by other observers. The external auditory meatus is a very small, tortuous passage capable of valve-like closure. In the fœtus there is no trace of the ceruminous mass found in the adult. The tympanic membrane is of the ordinary mammalian type, attached by its margins to the tympanic ring, concave externally, and attached to the manubrium mallei by a triangular fold which appears to be a protrusion of the membrane itself. The ossicles present no peculiarities. There is a well developed tensor tympani present, a fact which has not before been noted. The cavum tympani is filled by a mass of cavernous tissue which is thought to have the function of regulating pressure in the middle ear during submersion of the animal. The internal ear shows a well developed semicircular canal system and a cochlea of nearly three turns.

In considering these structures as an apparatus for hearing we see at once that all possibility of hearing by air conduction is shut off. It seems as if rather elaborate precautions had been taken to prevent this. In this connection it is interesting to recall that in diseased conditions of the conducting apparatus in human beings the hearing by bone conduction is increased and prolonged. It may well be said that in whales the closing off of the external auditory meatus increases the possibility by bone conduction, on which they must depend for hearing water-borne sounds. These are probably conveyed to the cochlea through the prominent mastoid process which occupies a considerable extent of surface between the squamosal and exoccipital bones.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

24 January, 1916

The Section met at 8:30 p. m., in conjunction with the American Ethnological Society, whose president, Dr. P. E. Goddard, presided.

The following program was presented:

Franz Boas, General Ethnological Notes from Porto Rico
Robert T. Aiken, Porto Rican Burial Caves.
H. K. Haeberlin, Archeological Work in Porto Rico.

Summary of Papers

Mr. **Aiken** stated that the archeological work done during the past summer was in two sections, the first being the excavation of a cave and adjacent village site, the second the excavation of a much larger site. The following data refer only to the former undertaking, which was carried through with the coöperation of Dr. J. H. Mason and under the general direction of Professor Franz Boas. The cave in question is one of the innumerable hollows in the limestone formation which composes a large portion of the island. It lies in a ridge about ten miles from Utuado, at an elevation of about two hundred feet above the adjacent valley. The entrance is large and faces east. The floor was entirely excavated. It was composed of alternate layers of disintegrated limestone and crystalline calcite with a thick underlying stratum of clay. The upper forty inches of the stratified formation yielded no less than twenty fairly complete human skeletons, all evidently interred in contracted position. All the remains were quite fragile but hardened on exposure to the air. Only three intact skulls were found. A few scattered bits of potsherd were found, as well as a few fragments of stone and shells. The village at the foot of the hill yielded nothing but a few similar sherds, a single hammer stone and a few pebbles. However, the fact of there being a site here was proved by the presence of prehistoric walls.

The conclusions to be drawn from the material are that the Porto Ricans practised cave burial, but did not use such caves for habitation and did not place offerings with the dead.

Dr. **Haeberlin** stated that a ball-court near Utuado was studied as part of the same expedition of which Mr. Aitken was a member. On the north and south the court was bordered by a continuous row of flat stones from one to three feet; on the east and west no stones were found. Red pottery with incised scroll work occurred. In a cave excavated by the speaker enormous quantities of snail shells, rodent and crab bones were found, together with many potsherds of a type different from the ball-court variety in texture, in the absence of incised decoration, and in the presence of inside handles. A baby burial was unearthed.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

7 February, 1916

The Academy met at 8:15 P. M. at the American Museum of Natural History, Vice-President Ernest E. Smith presiding.

The minutes of the last meeting were read and approved.

The following candidates for membership in the Academy, recommended by the Council, were duly elected:

Active Members

Miss Mary C. Dickerson, American Museum of Natural History,
Pierre A. Bernard, 662 West End Avenue,
Howard L. Clark, North Farm, Bristol, R. I.,
Howard Notman, 136 Joralemon Street, Brooklyn.

Associate Members

C. L. Camp, Columbia University,
A. M. Brown, Columbia University.

The Secretary reported the following death:

Mr. Ignaz Matausch, Active Member since 1914, died 14 December, 1915.

The Acting Recording Secretary presented an informal statement regarding plans for the Centennial Celebration of the foundation of the Academy, to be held in May, 1917. The Council has been organized into committees, which are to deal with different parts of this celebration. It is intended that a fund of at least $100,000 shall be raised, the income of which is to be employed for scientific investigations. As an initial gift, Professor N. L. Britton has generously promised $5,000.

The Academy then adjourned.

Henry E. Crampton,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

7 February, 1916

Section met at 8:20, Vice-President Ernest E. Smith presiding.

The following program was presented:

A. J. Goldfarb, Chemical and Physical Changes of Eggs and Their Significance in Grafting.

Arthur E. Hill, Report on the Absorbing Power of Certain Colloids.

Summary of Papers

Professor **Goldfarb** stated that when eggs of sea-urchins (*Toxopneustes variegatus*) are removed from the ovaries and placed in sea water at room temperature (84° F.) a series of changes take place that affect the character of the fertilization membrane, the rate of fertilization membrane formation, the viscosity of the egg protoplasm, and the rate of cleavage. These changes are approximately in proportion to the time factor, reaching a maximum just before death. These changes permit of ready fusion of separately fertilized eggs, whose further development into fused larvæ was elsewhere described.

Professor **Hill** stated that absorption occurs when chromium, iron or aluminum are precipitated by ammonium chloride and ammonium hydroxide in the presence of salts of cobalt, nickel, manganese or zinc. Using 100 mg. of the absorbing metal, it was found that as much as 40 mg. of nickel would be so completely absorbed as to be undetectable in the filtrate. The order of absorbents, from greater to less, is as follows: chromium, aluminum, iron; and the metals absorbed are in the order nickel, zinc, manganese and cobalt. It was found that the absorption is roughly proportional to the alkalinity. Moderate excess of ammonia will increase absorption so greatly that chromium hydroxide will carry down more than its own weight of nickel or zinc salts. In keeping with this generalization, it was found that separation of the two groups of metals by use of solid barium carbonate reduces the absorption greatly and the separation by sodium acetate in slightly acid solution reduces the absorption to an almost undetectable amount. A precise study of absorption of cobalt salts by pure chromium oxide suspensions was also made and followed the usual absorption isotherm, the equilibria being reached both from the side of excess in solution and that of deficiency in solution.

Dr. Mutscheller, in discussing Professor Hill's paper, found the results in full agreement with his own conclusion. The question whether the results given have been substituted in the exponential absorption equation was answered in the negative. Dr. Mutscheller believes that if these substitutions had been made in this equation, different values for the constant of equation for each one of the three colloids would have been obtained. This constant is known to depend on the temperature, the nature of the dispersion medium, and the dispersoid. This fact would preclude that each one of the three colloidal hydroxides possesses a different absorption potential or affinity, by reason of which an increase or decrease of the [OH—] concentration would produce proportional results. This seems to be the case in the data given by Professor Hill, for the values given in the columns show all proportional changes.

Dr. Mutscheller in his work on reversible colloids found by conductivity measurements that they absorb ions. Moreover, by means of potentiometric determination of the ionic concentrations, he found that they absorb specifically oppositely charged ions and leave the other ion free so long as certain limits of low concentration are not surpassed. Professor Hill's data seems to demonstrate the same fact. An increase of acidity and consequently hydrogen ion concentration, therefore, neutralizes the absorption affinity of the colloids so that other cations, namely, the metal salt in solution, are no longer absorbed by the colloid.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF BIOLOGY

14 February, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

R. W. Shufeldt, The Cahou and other Extinct Petrels. (Presented by Dr. F. A. Lucas.)

J. D. Kernan, Jr., The Chondrocranium of a 20 mm. Human Embryo.

A. J. Brown,	THE DEVELOPMENT OF THE SPINE IN THE CAT.
J. T. Nichols,	ON PRIMARILY UNADAPTIVE VARIANTS AMONG VERTEBRATES.

SUMMARY OF PAPERS

Dr. **Kernan** stated that the chondrocranium presents at this stage fairly complete development of the base of the skull in the region of the posterior and middle fossæ. There is no skull floor to the anterior fossa. The lateral occipital regions are united to the basal region by two roots which embrace the hypoglossal foramen. On the left side this foramen is partially subdivided. There is some evidence in this embryo for the view that the vertebræ entering into the formation of the occipital region are of the atlas type. By this hypothesis is best explained the subchordal position of the basioccipital, and the relations of the suboccipital nerve and the costal and transverse processes of the occipital vertebra to the condyle. The paraoccipital process and the lamina alaris of the lateral region may be analyzed on the evidence found in this fœtus into the costal and transverse process of the occipital vertebræ.

The otic capsules are well developed and they form with the parietal plates which surmount them a considerable part of the side wall of the skull, which contrasts markedly with their basal position in the adult. In the orbito-temporal region the sphenoid body is a solid mass of cartilage. There is a well developed dorsum sellæ, and sella turcica. The lamina hyochiasmatica, which in earlier embryos is on a level with the floor of the sella turcica, is elevated. The optic foramina are not yet surrounded by cartilage, the alæ orbitalis being unconnected with the præsphenoid. There are well developed alæ hyochiasmatica free from both præsphenoid and alæ orbitales.

The alæ temporales show separation into two parts, the processus alaris related to the basisphenoid, and an independent processus ascendens. The processus alaris is extended to the cochlea by a commissura alicochlearis. The foramen rotundum is complete, the foramen ovale only indicated.

In the ethmoidal region the septum nasi is well developed. The nasal walls, however, are merely small plates of cartilage with only slight inrolling of the ventral edges to indicate the maxillo-turbinals. There is no nasal roof or floor.

Ossification has begun in two bones only, the maxilla and mandible.

Meckel's cartilage is a massive structure, continuous dorsally with the malleus which shows manubrium and caput. The incus shows all its processus. The stapes is of younger tissue than the other ossicles, and is still connected by an "interhyale" to the dorsal end of the hyoid cartilage.

Mr. **Nichols** stated that his paper deals with vertebrate *variants* (forms or species of animals more or less related but differing from one another) which, although geographical, are not direct or obvious responses to the environment.

Several types of variant are defined. Representative forms occupying adjacent regions are designated as *adjacent* races or species; forms intermediate in structure between adjacent forms and occupying territory remote from them as *foreign intermediates;* related forms occupying the same territory and contrasted in superficial characters as *complements;* forms separated geographically and showing greater resemblance (not induced by environmental adaptation) than their degree of relationship would presuppose, as *outcrops.*

The hypothesis was advanced that, probably on account of competition, closely related forms are antagonistic. That is when in touch geographically they tend to force one another apart in superficial characters. If this hypothesis, which seems to fit into certain known facts extremely well, be accepted, it involves a centrifugal force in evolution opposed to the centripetal tendencies of blood relationship.

It is the main theme of the paper to advance the concept of these two forces as the fundamental framework of evolutionary control, the helm which is swayed by natural selection or other forces.

The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

21 FEBRUARY, 1916

Section met at 8:20 P. M., Vice-President Douglas W. Johnson presiding.

The minutes of the last meeting of the Section were read and approved.

The following program was presented:

S. H. Knight, CLIMATIC CONDITIONS IN SOUTHERN WYOMING DURING DEPOSITION OF THE "RED BEDS."

Charles P. Berkey, UNSTABLE CONDITIONS EXHIBITED BY SOME OF THE ROCK FOUNDATIONS OF THE HUDSON VALLEY.

Summary of Papers

Mr. **Knight** stated that the "red beds" consist principally of sandstone, arkoses and conglomerates, with smaller amounts of limestone and gypsum. They outcrop over hundreds of thousands of square miles in the territory embraced by Wyoming, Colorado, New Mexico, Kansas, Oklahoma, and Texas. They are late Pennsylvanian in age. Mr. Knight attempted to prove that the "red beds" are for the most part continental in origin, and that the climate was arid to semi-arid. By means of type geological sections A and B some fifty miles apart, by three block diagrams illustrating the relief at various stages in the history of the region, and by ten lantern slides the speaker proved his contentions. In summing up, Mr. Knight stated that heretofore the "red beds" had been regarded as of marine origin, rather than of continental. His presentation of the subject argues for the torrential, fluvial, and æolian origin of the greater part of the deposite instead of the marine one. The Upper Pennsylvanian age of the lower 800 feet of the "red beds" was determined from a pelecypod fauna found in the thin limestone member of Section A. The paper was discussed by Doctors Grabau, Finlay, Johnson and Reeds.

Dr. **Berkey** stated that the rock formations penetrated by the various tunnels of the Aqueduct were at many places not at all stable. The causes of instability are chiefly of two kinds. First: The excessive rock decay, represented both by badly fractured crush zones through which water has circulated to considerable depth, and also a few places where superficial decay matters of pre-glacial origin are still preserved beneath the drift. Very many crush zones with weakened material were encountered. The most extensive development of weathered rock of superficial relations was in the vicinity of Garrison in the Highlands, where the tunnel extended for several hundred feet through such material. Second: A type of instability of very different character is represented by rock which is under strain and which tends to relieve itself when the support is removed, as happens in the case of tunneling or shaft construction, allowing slabs to break off from the walls sometimes with considerable suddenness and noise. This is called "popping-rock" by the workmen and has been a source of considerable danger. It has been observed in several different formations, most prominently in the Esopus shales, the Storm King granite, and the Ravenswood granodiorite. The author undertook to explain in some detail the condition exhibited at one of these places in the vicinity of Cornwall on the Hudson, where it was found that there was movement in the rock through which the tunnel passed, after the concrete was placed and put under test. Various explanations have been suggested for this movement, and consequent leakage from the tunnel. Dr. Berkey's explanation involved the question of the movement dependent upon this known tendency of the rock to relieve the strain under which it is subjected. It is thought that the bursting pressure of the water when the test was made tended to add to the natural tendency of the rock, and the result was a movement which, except for this help, would probably not have taken place. Movement to the extent of jostling the blocks in the complexly fractured granite was aided by the escaping water, which tended to wash out the soft claylike gouge which normally fills many of the crevices or joints. The chance of being able to stop the leakage under these circumstances seemed so remote that it was finally decided to construct a new section of tunnel at this point at a lower level, to avoid the unstable condition that had been encountered. The interesting phenomenon from a geological standpoint is the fact that the rock had the appearance at all times during construction of being one of the most substantial and stable sections in the whole Aqueduct line.

The Section then adjourned.

Chester A. Reeds,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

28 February, 1916

The Section met at 8 p. m., Prof. R. S. Woodworth presiding.

The minutes of the last meeting of the Section were read and approved.

The following program was presented:

Russel L. Gould, Tests of Manual Accuracy of Pre-vocational School Boys.
G. C. Myers, Association and Classification.
Edith F. Mulhall, Tests of the Memory of School Children.
J. L. Stenquist, Tests of Mechanical Ability.

Summary of Papers

Mr. **Gould** stated that the tests were undertaken for the purpose of offering some possible data on the efficacy of the newly established Ettinger Pre-vocational Schools of New York City, in improving the general manual accuracy of the boys. The problem resolved itself into a new aspect of the old question of transfer from practiced abilities to unpracticed ones.

The plan was to test at the beginning of the school year two groups of boys; one group of those just beginning the pre-vocational shop work, and the other a control group of academic boys of the same grade and school. At the end of the year the tests are to be repeated. In so far as they are a reliable index of general motor ability, they are expected to indicate some effect of the shop work.

The necessity for large groups and for moderate haste prevented the use of more than three tests on each boy. Those used were the Thrusting, the Hammering and the common 3-hole test. The first two were designed for this work.

The Thrusting test required a full arm movement; to hit with a pencil the middle target of a row of three varying targets, thirty rows appearing from behind a screen at a constant speed. Four groups of thirty were used at four speeds, such that each row was in sight for 1.0 sec., 1.2 sec., 1.6 sec., and 2.0 sec. Each hit was separate and distinct, as one row only was in sight at a time. The number of hits ranged from 0 to 21.

In the Hammering tests the subject used a specially prepared hammer, to hit three points, distant from each other by 50 cm. Time was constant, measured by the beats of a metronome, at the average rate preferred by ten boys. An improvement in the apparatus records each hit electrically on a kymograph. There were very marked differences in the abilities of the boys, the hits ranging from 0 to 20 in 50 shots.

The 3-Hole test was too well known to be described. Time was taken for 50 contacts.

Mr. **Myers** stated that the purpose of this study is to investigate the natural tendency of classification as shown by the superior speed in naming (within certain limits) successive individuals of a single class over the speed of naming single individuals of successive classes.

In the preliminary test each of 71 normal school girls was supplied with a copy of 2 series, each of 10 class names of familiar things (Group I). These two series interchanged reappeared on the opposite side of the page (Group II). About half the subjects were given 18 seconds to write the names of things falling under each of the 10 class names of the first series. Then for the second series they were given a total of 180 seconds to write successively under each of the 10 class names, one name at a time, as many individual names as possible. For the other half of the subjects the procedure throughout was reversed.

The successive association under single class names may be called *less controlled*, the other *more controlled* associates. In the 3 minutes the average total number of words given for group I as *less controlled* associated is 56.4, M. V. 5.8, with a range of from 34-80 words. For *more controlled* associates the respective figures are 46.1, 4.9 and 20-60. For group II the *less controlled* associates give 60.4, M. V. 6.5, and a range of from 39-77 words; the *more controlled* 42.5, 4.0 and 32-58 respectively. This test is unfair to the *less controlled* records because of time lost in writing.

In a second experiment on 56 more girls the subjects were divided into pairs, each member of the pair serving as subject and experimenter in turn.

The writer read 20 class names pausing 8 seconds for each name while one of each pair named as many individuals of that class as possible. Number two recorded the number of individual names given. Then number one was provided with a list of these 20 class names and on signal she named an individual of each class name, repeating the operation until interrupted by writer at the end of 2 min. 40 sec. Number two recorded the number of responses as before. Then number two proceeded in reverse order with number one as recorder.

In the 2 min. 40 sec. the average total number of individual names given is for *less controlled* associates 123.7 M. V. 13.8, range 89-182; *more controlled* associates 66.9, M. V. 9.7 and 53-106. Four subjects studied practice effect by repeating the test 9 times, over a period of several days. Three found an increase in the total number of associates of each type and the superiority of the less controlled associates increased with time. For the other subject both decreased with time.

These facts emphasize a fundamental difference between the two types of associates and the rather obvious inference that classification is a very natural process. The study is still in progress.

Miss **Mulhall** stated that an attempt was made to determine whether or not there are any characteristic differences between the two memory processes known as recall or reproduction and recognition. Answers were sought to the five following questions: 1—Does the person who recalls one kind of material well also recall another kind of material well; or what is the correlation between the recall of different materials? 2—Does the person who recognizes one material well also recognize another kind as well; or what is the correlation between the recognition of different materials? 3—Does the person who recalls one material well recognize that material well; or what is the correlation between the recall and recognition of the same material? 4—Are the recall records of girls better than those of boys as earlier literature states? Is there any sex difference in recognition memory? 5—Is there any difference in the sex variability in recall or in recognition?

The subjects were 192 children, 71 in grade 5 B, 62 in 6 A and 59 in 6 B in a city school. The materials used were two series each of 25 words, 25 forms, 25 syllables. Memory was tested half the time by requiring the subjects to write down what they remembered (reproduction) and half the time by asking them to select from another set the items which they had and had not seen (recognition).

The conclusions were: 1—A person who can reproduce a great many items of one material cannot necessarily reproduce many of another material. 2—The person who can recognize one material well cannot necessarily recognize another material well. 3—A person who secures a high score for recalling words, forms, syllables may not necessarily receive a high score for recognizing words, forms, syllables respectively. (In no case was the average of the coefficients of correlation as high as .30.) 4—There is found no superiority of the girls over the boys for recall, but a confirmation of the work of Chamberlain. There are no sex differences for recognition. 5—There is no consistent difference in sex variability in recall or in recognition.

Mr. **Stenquist** stated that his report consists chiefly of a description and exhibition of a series of mechanical tests which have been devised by the author under the direction of Professor Thorndike. The first of these is called Construction Test, Series I, and is described in detail in "The Intellectual Status of Children who are Public Charges," Archives of Psychology No. 33, Columbia University. Construction Test, Series II, is similar to Series I, but more difficult. These tests consist of a series of mechanical models to be assembled under standardized conditions by the subjects, the original idea being to provide a test that did not depend upon the subject's ability to read and write, and to deal with heard words. In the case of Construction Test, Series I, age-grade standards have been built up and the child can be scored as over or under a standard "Construction-age", as determined by the scores of 432 public school children of New York City.

The second type of test reported upon has been named "Recognition of Mechanical Devices," and consists of 55 mechanical devices, ranging from a common nail to a spark plug and its parts, all numbered and fastened to a card about 8 by 18 inches, placed in a suitable box. A complete list of the names of all the devices is given the subject and his task consists in identifying each device known to him, which he does by writing the appropriate number before each name.

Both of these tests have only been begun and the data thus far gathered does not warrant any further conclusions than those reported in the monograph referred to above.

Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

6 March, 1916

The Academy met at 8:15 p. m. at the American Museum of Natural History, Vice-President Ernest E. Smith presiding.

The minutes of the last meeting were read and approved.

The following candidate for Associate Membership, recommended by the Council, was duly elected:

Adolph Elwyn, Hoagland Laboratory, Brooklyn.

The Secretary reported the following death:

Nathaniel C. Nash, Life Member since 1910, died 10 October, 1915.

The Academy then adjourned.

Henry E. Crampton,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

6 March, 1916

Section met at 8:20 p. m., Vice-President Ernest E. Smith presiding.

The following program was offered:

Victor C. Myers, The Chemical Composition of the Blood in Diseases of the Kidney.

James P. Atkinson, Food Poisons.

G. A. Reichling, Unusual Meteorological Conditions Observed During a Winter-Flight in a Tractor Biplane.

Summary of Papers

Dr. **Myers** stated that normally the non-protein nitrogen of the blood in the human subjects amounts to 25-30 mg., the urea nitrogen to 12-15 mg., the uric acid to 2-3 mg., the creatinine to 1-2.5 mg. and creatine to

5-10 mg., all calculated per 100 cc. of blood. The ease of excretion of the three most important nitrogenous waste products—creatinine, urea and uric acid—seems to fall in the order just named, possibly owing to purely physical laws of concentration and solubility. In gout, where the permeability or activity of the kidney is only slightly lowered, we encounter an increase only in the uric acid concentration of the blood (4-9 mg. per 100 cc.). In the early states of chronic interstitial nephritis a similar retention of urea is observed. Here, however, we begin to find a retention of urea as well (urea nitrogen figures from 15-35 mg. per 100 cc.), although, as yet, there is very little influence upon the creatinine. As the disease becomes more severe, the retention of urea increases (60-80 mg.), although, with improvement, it falls. Creatinine, however, is normally excreted with such great ease that it is apparently only in the last stages of the disease that a notable retention occurs, figures over 5 mg. per 100 cc. indicating, as a rule, an early fatal termination. The blood creatine has been found increased in only a few cases, viz., terminal cases of interstitial nephritis with very high figures for uric acid (13-27 mg.).

The retention of the nitrogenous waste products is frequently of less immediate concern than the retention of acid substances. As an indication of the actual severity of an acidosis, we recently found Van Slyke's method of ascertaining the CO_2 combining power of the blood plasma of very great value.

In the early cases of diabetes the glucosuria is a very reliable guide as to the hyperglucemia, although quite the reverse may be true in cases of long standing with nephritic complications. Here one may encounter very high figures for blood sugar with a very small amount, or even no sugar in the urine. In one case the blood sugar of 1.10 per cent., ten times the normal, was observed with only 0.5 per cent. of sugar in the urine. In such cases the estimation of blood sugar is of greater value than the urine sugar.

Mr. **Atkinson** outlined his paper as follows: 1. Definition of Foods and Poisons. In general, Foods comprise those substances which taken into the body go to or assist in building up the body cells and furnish energy. Poisons are those substances which taken into the cells interfere with its normal metabolism.

Foods	*Poisons*
Animal	Animal
Vegetable	Vegetable
Mineral	Mineral
Synthetic Organic Compounds	Synthetic Organic Compounds

Foods may become poisons under certain conditions and, vice versa, poisons may become foods. Certain foods (protein) may predispose (sensitize) for subsequent poisoning by the same food. Certain generally accepted food substances may possibly become the source of serious or fatal illness through refinement in manufacture—that is, by the removal of some necessary constituent, as the removal of the pericarp in polishing rice (so-called deficiency diseases).

2. A brief enumeration of food poisons, including preservatives and heavy metals.

3. Discussion of the action of heavy metals as poisoning agents and demonstration with guinea pig showing that the normally toxic dose of mercury (as an example) is very much diminished if first treated with protein—that is, protein first fixing the metal prevents its action. A brief summary of the fixing power of heavy metals by protein with the conclusion from experimental data that the toxicity of certain heavy metals appear to be functions of their combining powers with protein—that is, the firmer the combining power the more toxic is the metal.

4. Deficiency diseases.—The demonstration of polineuritis in a pigeon fed exclusively on polished rice.

5. A brief discussion of idiosyncrasy of foods; the theory of anaphylaxis for idiosyncrasy to protein foods with a demonstration of anaphylactic shock in the guinea pig sensitized to horse serum.

Mr. **Reichling** stated that a flight was made about 2:30 P. M. January 15, 1916, in a Huntington military tractor at the hangars of the Huntington Air Craft Co., Garden City, L. I. The pilot was P. C. Millman of the Areo Club of America. Mr. Lacey, Mr. Vincent Armor and several mechanics were witnesses. The afternoon was quite cold and slightly cloudy. Ground temperature perhaps 15° F. The time of flight was ten minutes. Distance covered about 12 miles. Maximum altitude about 1600 feet. They passed through mist and some low hanging clouds and could see a considerable portion of the island at maximum altitude spread out in contour style. The air was quite clear above 1,000 feet. The speed of the ascent was about 800 feet per minute (perpendicular). No difficulties were caused by air conditions. Mr. Reichling found street clothes adequate with exception of cap, and it would have been easy to make various scientific observations just as readily as on the ground. The author believes that it will be possible to make observations throughout the year in this way, to test the feasibility of wireless apparatus, to study solar spots or prominences during total eclipses, etc. Air-samples at different altitudes, studies in ionization, cosmic dust and map-making show how various the possibilities of these flights might be, with the proper instruments.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF BIOLOGY

13 March, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

W. W. Browne, The Bacteriology of Air.
George G. Scott, Oxygen Utilization in Fishes.
F. H. Pike, The Significance of Certain Internal Factors in Organic Evolution.

Summary of Papers

Dr. **Browne** stated that determinations of the microbic content of the atmosphere were made under the direction of Prof. C-E. A. Winslow, Chairman of the New York State Commission of Ventilation. A total of 385 samples of air were examined during the first six months of 1914, obtained from four different groups of sources: country (85 in number), city (135), office (87), factories (47). The samples of air were collected and examined by the methods prescribed by the Committee on Standard Methods for the Examination of Air of the American Public Health Association.

Summary

Source.	Number.	Microbes Per cu. ft. 20° C.	Microbes Per cu. ft. 37° C.	Streptococci 100 cu. ft.
Outdoor:				
Country	85	56	30	12
City	134	72	32	11
Indoor:				
Office	87	94	80	22
Factories	47	113	63	43

The microbes include both molds and bacteria.

Conclusions.—The number of bacteria developing at 20° C. from outdoor air is generally under 50 per cubic foot and rarely over 100.

The count at 37° C. for such air is about half that of 20° C. and rarely over 50 per cubic foot.

The air of occupied spaces shows larger average numbers of micro-organisms and greater fluctuations. The 20° C. count may average over 100 per cubic foot and may reach 700 or more. The 37° C. count averaged over 50 in the factories and offices. Mouth streptococci are more abundant in the indoor air, ranging from 20 to 40 per 100 cubic foot of air.

Dr. **Scott** stated: *A*. Lowering of the temperature causes a reduction in the rate of oxygen consumption. *B*. Oxygen was consumed more rapidly in tall, narrow vessels of water than in broad, shallow ones. *C*. Fishes kept in dark vessels apparently consume oxygen at a less rapid rate than those exposed to light. *D*. Some forms show more resistance to low oxygen supply than others. This is particularly true of invertebrates. Respiration ceases altogether, and commences again if the specimen is returned within certain time limits to aërated water. The toad fish and killifish live in water with low oxygen content, while a butterfish and menhaden quickly succumb to reduction of oxygen supply. *E*. Most marine invertebrates consume oxygen at a very low rate; fishes at a much higher rate; with amphibia the rate is between that of invertebrates and fishes; the rate with mammals and birds is relatively high, that of birds being extremely high as compared with anatomically lower forms.

Professor **Pike** stated that the changes which occur in animals and plants may be divided as follows:

1. Changes of form—growth and development, ontogenetic and phylogenetic.
2. Changes of position—the phenomena of movement.
3. Changes of material and energy.

There are many contributions to the study of evolution from the standpoint of changes in form and changes in position and but few from the point of view of changes in matter and energy. The effect of environment upon the organism is manifested through the changes in matter and energy. Injurious substances in the environment may slow down or stop the processes occurring in living matter. The failure of moisture may mean death or encystment. A low temperature means a slowing down of life processes, a suspension of activity or death. Distribution of an organism is restricted to a region in which a given set of conditions exists. Herbert Spencer pointed out the fact that some organisms have acquired a certain degree of independence of the environment. My own interest in the subject relates to the mechanisms by means of which this independence of the environment is secured. The study of the effects of the environment may be taken up in terms of the changes in internal conditions. If the environment really does affect these internal conditions, we have the possibility that the environment is one cause of variations. The questions of adaptation, the struggle for existence, the survival of the fittest and geographical distribution may all be approached from this point of view.

The paper was discussed by Dr. E. L. Scott.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

20 March, 1916

Section met at 8:15 p. m., Vice-President Douglas W. Johnson presiding. The minutes of the last meeting of the Section were read and approved.

The following program was presented:

Willis T. Lee, Application of Physiographic Methods to the Correlation of Non-marine Formations in the Rocky Mountains.

Summary of Paper

Dr. **Lee** described his attempt to work out the sequence of events during the physiographic evolution which resulted in the stratigraphic and structural relations now observed in the rocks of the Mesozoic age in the mountain region. The ancestors of the present Rocky Mountains were eroded during Triassic and Jurassic time and late in the Jurassic period they were reduced to a peneplain. On this plain were spread out the continental deposits which constitute the La Plata sandstone and its age equivalents. The lower parts of the plains were covered with sea water in the later part of the Jurassic period. In the sea, where the water was suitable for marine organisms, there accumulated the fossiliferous beds which now are called Sundance. However, the sea water found its way landward over the nearly level plain far beyond the places favorable for the life of marine organisms and gathered in shallow bays where, by evaporation, it became unsuitable for habitation. There are beds of limestone and gypsum within the La Plata group which seem to have been classed by some geologists with the underlying red beds and by others with the overlying Morrison, and may be due to the spreading of the Jurassic sea over the peneplain.

The Section then adjourned.

CHESTER A. REEDS,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

27 MARCH, 1916

Section met at 8:15 P. M., in conjunction with the American Ethnological Society, Dr. P. E. Goddard presiding.

The following program was presented:

A. A. Goldenweiser, NOTES ON MELANESIAN ORGANIZATION.*

The Section then adjourned.

R. H. LOWIE,
Secretary.

BUSINESS MEETING

3 APRIL, 1916

The Academy met at 8:20 P. M. at the American Museum of Natural History, President Michael I. Pupin presiding.

The minutes of the last meeting were read and approved.

The following candidate for Active Membership in the Academy, recommended by the Council, was duly elected:

Lucius P. Brown, City Health Department.

The Academy then adjourned.

HENRY E. CRAMPTON,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

3 APRIL, 1916

Section met at 8:20 P. M., Vice-President Ernest E. Smith presiding.

The following program was presented:

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* Science, Vol. XLIV, 1916, pp. 824-828.

George B. Pegram, Are There Atoms of Light?—The Quantum Theory.

Summary of Paper

Dr. **Pegram** discussed the several experimental facts that have led to the determination of a certain universal constant, usually referred to as Planck's "h", and the attempts that are being made to work this constant into physical theory; how the fact of this constant means that the atomic mechanism of radiation and absorption of light or other electromagnetic radiation involves the transfer of elementary discrete quanta of energy, the magnitudes of these quanta being directly proportionate to the frequency of the vibration; the irreconcilability of the quantum theory with the formerly accepted theory of the equi-partition of energy; the quantum theory as apparently incompatible with the accepted laws of mechanics.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF BIOLOGY

10 April, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

H. B. Williams, An Electrical Theory of Nerve Impulse.
H. von W. Schulte, The Morphology of the Azygos Veins.

Summary of Paper

Professor **Schulte** stated that the azygos veins, contrary to the implication of their name, are originally paired channels developed in the plexus about the anlages of the vertebræ and constituting when fully formed a series of anastomoses between segmental veins which extend from the head to the root of the tail. These serial anastomoses make their first appearance in embryos of sauropsids where they develop as a collateral channel for the drainage of the body segments as the regression of the mesonephros entails a reduction of the posterior cardinal vein. Coincidentally a second longitudinal vessel on each side emerges from the abundant plexus about the neuraxis within the spinal canal, and this too receives blood from the segmental veins. These two sets of channels, intravertebral or spinous, juxtavertebral or azygos, agree in drainage area, in the rationale of their development and in having connection with the districts both of precava and of postcava, between which they so extend as to be able to serve as an equilibratory anastomosis tending to equalize conditions of flow in the two great drainage areas of the systemic veins. Both have numerous connections across the vertebræ with their antimeres. In the case of the azygos the enlargement of some of these connections permits of the development of asymmetry and the ultimate preponderance of the vein of one side. This, as might be expected from the normal dextral position of single pre- and postcavæ, is usually the right and presumably the factor common to all three cases in the early shift of the venous end of the heart to the right. While appearing first in embryo sauropsids in many and perhaps the majority of adult forms the azygos is reduced and this seems to depend in general upon the selection of the spinous channels as the favored line for segmental drainage; a more variable factor exists in the establishment of connections between the right azygos and portal tributaries first in the caval lobe of the liver, later very generally in the extent of the foregut.

The *locus classicus* for the history of the azygos is Rathke's study of the development of *Tropidonotus natrix*. He also investigated the conditions in birds. Later Hochstetter examined the subject in several lacertilians. In all it appears that the cervical portion of the system becomes included in the costo-transverse space giving rise to the anterior vertebral vein. The same position may be occupied by the posterior vertebral vein where the costocentral articulations are present as in birds and for three segments in saurians (Rathke). This position is secondary and depends upon the interruption of the plexus about the vertebræ by the developing capitela with the persistence of the portion of the plexus included between rib and transverse process. Chelonians stand apart from other sauropsids in that they develop a homodynamous vessel dorsal to the transverse processes.

In mammals essentially similar conditions obtain, as Rathke pointed out in 1837. A series of anastomoses extends on each side of the spine from occiput to tail connected across the vertebræ by numerous anastomoses. The whole system has been termed the supracardinal veins by Huntington and McClure, to whom we owe the recognition of its participation in the formation of the postrenal segment of the postcava in placentals. It was later termed prevertebral plexus by Huntington. From this plexus the azygos developes in a manner analogous to its formation in reptiles. This was recognized by Rathke, who interpreted the azygos as a new or secondary vein retaining only the termination of the postcardinal as its point of debouchment. Unfortunately in the following year Rathke modified his view and considered that the azygos was of postcardinal origin to the 8th or 10th intercostal space and only beyond that was what we should now term supracardinal. This error taken up by Huntington has obtained wide currency, though it has been corrected by Zumstein (1897) in the guinea-pig, by McClure in the opossum (1902) and by Sabin (1915) in the pig.

Among adult mammals the azygos may be bilateral as in monotremes and many diprotodont marsupials. It may be absent as in cetacea (v. Baer), in Cholœpus and Bradypus (Hochstetter). It is usually right-sided, but may be left, with or without the persistence of a left cava. Marshall and more recently Beddard have listed its conditions in many species. It is right-sided in Primates, Carnivora, Perissodactyla, Xenarthra except the sloths, in Hyrax and in Tragulus. It is left-sided in many polyprotodont marsupials, in Suidæ, in Moschinæ and in hollow-horned ruminants. Among rodents the right azygos is the rule; it is associated with a smaller left azygos in Hystrix, while in the beaver the vein of the left side alone persists. A specimen of this animal recently dissected at Columbia confirms Beddard's interesting observation. In general, bilaterality of the azygos is associated with low position (Beddard).

Döllinger, v. Baer and the earlier students of the vascular system generally were familiar with the plexiform character of the embryonic blood vessels and appreciated the rôle of hydrodynamic factors in formation of trunks by the selection of certain lines of flow from the multiplicity of possible channels afforded by the plexuses. Since Roux and Thoma the appreciation of the mechanical factor has become general and the importance of the drainage area in determining the proximal channel has been recognized. The peripheral plexus increases with the size of the part in which it lies, and with the differentiation of the part tends to acquire independence from the general plexus. The venous trunks become the indexes of the development and growth of their drainage areas and the pattern of the great veins is, as it were, the expression and integration of the specialization and relative growth rates of the various parts of the body, and is relative to the embryonic condition, a reduction and simplification, serving to promote mechanical efficiency by the diminution of surface friction by the substitution of a few large trunks for the numerous plexiform channels. As this is accomplished the general venous plexus becomes resolved into independent districts connected ultimately by feeble and variable anastomoses, *e. g.*, pulmonary, portal, portorenal, systemic, the latter subdividing into precaval and postcaval areas. Between these the spinous and azygos vessels act as equilibrating anastomoses (v. Baer), and are therefore brought into competition, a competition which in sauropsids results unfavorably to the azygos as a general rule, for here portal connections also tell against the azygos. Such connections in mammals are formed between the postcardinal and portal (Zumstein, Brown, Davis), but they are evanescent and antecede the appearance of the azygos, which maintains itself as a moderate sized and rather variable channel except in cetaceans and sloths. In these forms the spinal channels are of great size.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

17 April, 1916

Section met at 8:15 p. m., Vice-President Douglas W. Johnson presiding.

The minutes of the last meeting of the Section were read and approved.

The following program was presented:

George F. Kunz, Remarks on a Pseudo-meteorite, Iron Pyrite Crystals, and a Black Diamond.

George I. Finlay, The Geology of North Park, Colorado.

A. W. Grabau, Geology of the Island of Gotland in the Baltic Sea.

Miss Marjorie O'Connell, Notes on the Geology of Oesel in the Gulf of Riga.

Summary of Papers

Dr. **Kunz** stated that a pseudo-meteorite was sent to him for examination by Mr. Robert A. Creager, of Mount Orab, Ohio. It weighs four pounds and two ounces and is about the size and shape of a double hand. It is not a meteorite, but a piece of cast iron scorao. As it had been in the ground for some time it was thoroughly rusted.

A new locality for pyrite was found in the past few months at the Ibex Mines, Colorado. The crystals are of special interest because of their magnificent character and their frequently hemamorphic shape, two of the four faces being entirely cubic (*a*) and the plan of the crystals pentagonal dodecahedrons (*e*). The crystals are unusually compact of type cut into small jewelry and sold under the name of "marcusite" in the early part of the eighteenth century. One of the crystals weighed more than two pounds.

An irregular, cubic crystal of black diamond, weighing 138.75 carats and measuring 22.5 millimeters on each face, 11 millimeters in width and 6 millimeters in depth was found at the Jagersfontein mine. Although of cubic form, it is built up of rounded octahedral conglomerations.

Professor **Finlay** stated that North Park is located near the boundary line of Colorado and Wyoming. The rocks are of sedimentary and volcanic origin. The platform upon which the sediments rest is largely made of granite, and there are considerable amounts of gneiss and schist, and then comes the Farrell limestone, which is about 30 feet thick. Above it one finds about 1,500 feet of red sandstone. Next comes the Morrison, about 260 feet in thickness, and above this the Glen Cairen shales. Then comes the true Dakota, about 100 feet thick, and above is a rather complete series of Cretaceous beds, closing with the Pierre shales, 2,500 feet thick. The chief economic deposit found here is coal, which is quite phenomenal, having a thickness of 50 feet in some places in the Coalmont formation. Very little of it is mined, however, since it is too soft for commercial purposes.

The paper was discussed by Dr. Johnson and Mr. Knight.

Professor **Grabau** stated that the structure of the island of Gotland is very simple, being composed of slightly tilted limestone and shale beds with no faults in evidence. It is very rich in fossils. The Cambric, Ordovicic, and Siluric beds were deposited in this region in normal sequence. Subsequently the region was submerged beneath the water of the Baltic, except for the island of Gotland. Here two series of formations are in evidence, a lower in the north and an upper in the south. These two series, however, do not correlate one with the other, as some European geologists have tried to prove. Professor Grabau believes that the higher series in the south correlate with the Lower Ludlow of the English section. There is a break between the Upper and Lower Ludlow in Europe which is represented in America by the Salina. The Upper Ludlow is the equivalent of the Monroe of Michigan. The Lower Ludlow, Wenlock and Llandovery correspond to the American Niagara and

Medina. The Lower Ludlow is present in the south of Gotland and overlies the beds found in the north. It is perfectly evident if this interpretation is correct that the sea withdrew here, and that there was a period of exposure sufficiently long to permit of the removal of the beds, which are now absent in the northern part of Gotland. This is proved by the paleontology of the region, as well as by the physical character of the rocks, especially the sandstone, which is a sandstone of purely continental origin, and was in large part worked by the wind and corresponds to our Salina beds.

Miss **O'Connell** stated that in Pre-palæozoic time the Oesel region was composed of crystallines and was worn down to a peneplain. Upon this surface the sea advanced from the south and southeast. This peneplain was not perfect, it being a little irregular and slightly tilted. First came the Cambrian, then the Ordovician, then the Silurian, and at the end of the Silurian period the sea retreated; some of the continental deposits were spread out over the area. Then the region was peneplained. Erosion was caused by rivers flowing in a radial direction, which wore off a deal of the surface. Finally only two islands were left, Dago and Oesel, the rest of the region being submerged.

The most important fossils found here are eurypterids, which are world famous on account of their almost perfect preservation. Nothing has been changed in the preservation of these animals; even the hairs on the outer shell are intact. This horizon is only a foot or two in thickness, yet thousands of organisms compose the mass. These eurypterids were carried there by the rivers of that time. It is interesting to note that their nearest relatives are found in western New York, which are the second best preserved fossils in the world. This may be explained by the fact that in Palæozoic time there was a continent extending from North America to western Europe, which was drained by rivers interlacing with one another; this enabled the animals to migrate from one river to another. The New York formation is similar to the one of Oesel. There is a thin layer of limestone, which contains eurypterids, followed by a conglomerate of about one foot in thickness, which marks the break between the limestone beds of the lower and upper Ludlow.

The two latter papers were discussed by Doctors Grabau, Johnson, Knight and Reeds.

The Section then adjourned.

CHESTER A. REEDS,
Secretary.

BUSINESS MEETING

1 May, 1916

The Academy met at 8:23 P. M., at the American Museum of Natural History, Vice-President Ernest E. Smith presiding.

The minutes of the last meeting were read and approved.

The Acting Secretary read the following minute prepared by Professor **E. B. Wilson** relative to the death of Theodor Boveri:

Theodor Boveri, professor at the University of Würzburg and one of the most eminent honorary members of this Academy, died in Würzburg October 15, 1915, at the age of fifty-three years. A native of Bamberg, Germany, he studied at the University of Munich under Kupffer and Richard Hertwig and subsequently became privat-docent at that University. In 1893 he was called to the University of Würzburg, succeeding Semper as Professor of Zoölogy and Comparative Anatomy and Director of the Zoölogical Laboratory. Four years ago he was offered the chair of Zoölogy at Freiburg as successor to August Weismann and later was called to the directorship of the newly established research laboratory of the Kaiser-Wilhelms-Institute at Berlin; but both these offers he declined, remaining loyal to the laboratory which under the direction of Semper and himself had become one of the leading centers of biological research in the world.

Boveri's place among the illustrious leaders of biology is already assured, though his name is still not widely known outside scientific circles because of the abstruse and unfamiliar character of the researches to which his life was devoted. No investigator of our times has accomplished more to elucidate the intricate problems involved in the physical basis of heredity and the mechanism of development. His remarkable series of *Zellen-Studien,* beginning in 1887 and extending through more than twenty years, illuminated the whole field of cell-division, fertilization and maturation of the germ cells. He was the main founder of the theory of the individuality and genetic continuity of the chromosomes; and to his memorable researches on dispermic eggs is due the experimental demonstration of the qualitative differences of the chromosomes and their significance as primary factors in heredity. These researches, more than any others, opened the way to a cytological explanation of Mendel's law of heredity, and led him in the last year of his life to advance a highly suggestive new theory concerning the origin and nature of tumors. His work was as masterly in experimental embryology as in cytology, and will constitute an enduring landmark of progress on the history of investigations upon the organization of the egg, the role of protoplasm and nucleus, and in the modern controversies relating to vitalistic and mechanistic conception of development.

Boveri's name will stand with those of Schwann, Kölliker, Remak, Van Beneden, Flemming and the few other great leaders of microscopical research; and it may be doubted whether he has had an equal in respect to the keenness of his scientific insight or the fruitfulness of his labors in the difficult and fundamental field of inquiry. The more carefully we study his works the more is our admiration stirred by his qualities as an investigator. He was endowed with a mind fertile in ideas, of great logical acuteness, of perfect clarity; he was an observer of unsurpassed accuracy and resourcefulness; and beyond all this his work is everywhere permeated by that indefinable artistic quality which often characterizes scientific research of the highest type. With this rare combination of qualities he naturally and inevitably took his place among the foremost investigators of our time, and his work will endure as a classical model of creative insight, of fruitful scientific method and of lucid presentation.

With a deep sense of the loss that science has sustained through Boveri's untimely death the New York Academy of Sciences renders its tribute to his rare and lofty qualities as a man and records its appreciation of his brilliant original contributions to knowledge.

The Academy then adjourned.

Henry E. Crampton,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

1 May, 1916

Section met at 8:30 p. m., Vice-President Ernest E. Smith presiding.

The following program was presented:

J. H. Morecroft, The Electron Steam Amplifier—An Electrical Ultramicroscope.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

1 May, 1916

The Section met in conjunction with the New York Branch of the American Psychological Association at Columbia University.

The following program was presented:

Herbert W. Rogers, Some Emperical Tests in Vocational Guidance and Selection.*

Christine Ladd-Franklin, The Visibility of the Nerve Current.

T. T. Lew, Taboos in China.*

Samuel A. Tannenbaum, How Psychoanalysis Cures Nervousness.*

The Section then adjourned.

R. H. Lowie,
Secretary.

SECTION OF BIOLOGY

8 May, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

George H. Huntington, The Relation of the Lymphatic and Hæmal Channels in the Vascular System of the Vertebrates.

W. C. Clark, Some Phases of Bone Growth in the Adult.

Summary of Paper

Professor **Huntington** stated that the development of the thoracic ducts in all three amniote classes follows precisely the same main fundamental principle, viz., the formation of lymphatic channels by confluence of numerous originally separate intercellular mesenchymal clefts and spaces.

The reptile presents this genetic process in its simplest form, in a region in which systemic venous development is reduced to a minimum. In

* Abstracts published in Journal of Philosophy, Vol. XIII, 1916, pp. 662-665.

both the bird and the mammal the development of the thoracic duct becomes complicated by a direct or indirect relation of the lymphatic anlages to the adjacent elements of the hæmal (venous) vascular system. In the bird the relation of the lymphatic anlages to the hæmopoetic axial mesenchyme is *direct,* the avian thoracic ducts becoming for a time functionally *hæmophoric.*

In the mammalian embryo the relation of the developing thoracic ducts to the axial venous system is *indirect,* the lymphatic anlages replacing the temporary ventro-medial hæmophoric azygos tributaries *topographically,* but never themselves assuming the hæmophoric function.

In all three classes of amniote embryos the final results of the genetic processes outlined above is the same, viz., the establishment of a peri-aortic, or para-aortic, lymphatic channel, the amniote thoracic duct. In a wider interpretation it becomes evident that all the diversified phenomena of vascular ontogeny, hæmal as well as lymphatic, are focussed in the small field which any extra-embryonic vascular area presents.

The Section then adjourned.

W. K. Gregory,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

15 May, 1916

Section met at 8:15 p. m., Vice-President Douglas W. Johnson presiding.

The minutes of the last meeting were read and approved.

The following program was presented:

H. E. Anthony, Preliminary Report on Fossil Mammals of Porto Rico. (Read by Title.)

E. T. Hodge, Geology of the Coamo-Guayama Region, Porto Rico.

D. R. Semmes, Geology of the San Juan District, Porto Rico.

Chester A. Reeds, Fossil Faunas of Porto Rico.

Charles P. Berkey, Plans for Field work in Porto Rico during 1916.

Summary of Papers

Mr. **Hodge** stated that the Coamo-Guayama district is located in the east central portion of southern Porto Rico. The rocks of this area are complex. The stratigraphic series is made up of thousands of interfingering alluvial fans, deltas, estuarine and littoral deposits, which have been intruded by innumerable individual igneous bodies, all more or less metamorphosed, faulted and folded.

Across the northeastern portion of the area is a broad belt of rock believed to be Comanchic. The presence of *Cladophyllia furcifera* in a bed of limestone and of fossil leaves in an adjacent hematite bed point, according to Dr. Edward W. Berry and Dr. Frank H. Knowlton, to the Comanchic age of these beds. The basal portion consists mostly of tuffs; the upper portion, of shales and a few limestones. Between this belt of rock and the adjacent higher one there is a good evidence of a period of folding and erosion.

A conglomerate occurs at the base of the overlying belt of rocks. It forms the backbone of the Sierra de Cayey, the principal mountain range of Porto Rico. It is followed by alternating beds of shale and limestone with a few beds of tuff and conglomerates. No fossils were found in these beds, and it is assumed that they belong either to the Cretacic or the Lower Eocenic system. They occur in a belt which curves southward and eastward from the northwest corner to the southeast corner.

This is followed by a third belt, which is composed of a thick conglomerate at the base, followed by shales with several thick limestone members. In these beds was found a pelecypod, *Venericardia alticostata*, which is the typical index fossil for the upper Eocenic of the Gulf States. A period of considerable uplift and prolonged erosion followed the deposit of these sediments. Upon the peneplained surface of the underlying complexly folded series of rocks thick limestone beds were laid down. From this limestone Prof. Charles P. Berkey and Mr. D. R. Semmes gathered fossils, which Dr. W. H. Dall pronounced to be Upper Oligocene in age. In the Coamo-Guayama district this limestone is represented by one small remnant of erosion. Its former great extent is suggested by the superimposed drainage, which is now rapidly attaining structural adjustment. Additional uplift in very recent time is shown by river terrace deposits bearing fossils of recent age at elevations of 350 feet above the sea. The volcanic centers which broke through the Cretacic and Eocenic rocks are rather common features. All of these have been worn down to their roots and are represented at present by vents clogged with volcanic debris and surrounded by numerous intrusives and aureoles of hydrothermal alteration. It is thought that the hot springs of this area are the dying out phases of volcanic activity.

The paper was discussed by Dr. Reeds.

Mr. **Semmes** stated that the San Juan district lies on the northern side of the island of Porto Rico. It extends from the city of San Juan on the east to a point about two miles east of Manati and southward as far as Barranquitas—an area approximately 500 square miles in extent. The San Juan district is a typical N-S section through the northern half of the island, the geological history of which may be regarded as essentially the same as that of the whole island. The physiographic history of the San Juan district is that of a complex mountainous oldland, which has been peneplained, partially submerged, overlapped by a coastal plain, uplifted, maturely dissected, again slightly submerged and partially uplifted; erosion continued in the interior from the time of the first uplift. The formation of the district may be divided into a younger and an older series. The younger formation consists of a coastal deposit of indurated lime dune sand of presumably Pleistocene age which overlies unconformably a limestone series. This limestone series, termed the Arecibo formation, rests almost horizontal (dip, 6° N.) and is now maturely dissected, giving rise to the typical pepino or haystack topography of the island. The Arecibo formation is regarded as probably wholly Upper Oligocene in age. In the northwestern portion of the island, but not appearing in the San Juan district, is a lignitic shale member (the San Sebastian shale) which underlies the Arecibo formation. The age of this shale member is uncertain, but in all probability it is of Lower Oligocene age. The coastal plain has been carved out of the younger series. The older series consists of marine and volcanic sediments with numerous intrusives. It is highly tilted and locally folded, resting unconformably below the younger series. The sedimentary types represented are limestones, shales, sandstones, conglomerates, tuffs and ashes. All of these sediments are derived almost wholly from volcanic sources. Even the limestones show brecciated structure and are, with few exceptions, mere accumulations of limestone fragments derived from older beds shattered by volcanic outbursts. The foraminiferal content of certain shale and limestone beds in the upper part of the older series indicates that the beds are Upper Cretaceous and Eocene in age. The lower part of the series is no doubt Comanchic. The peneplaination of the older series, prior to the deposition of the coastal plain, culminated therefore in late Eocene time. The older series is everywhere intruded by igneous rocks of many varieties. The predominant type is an andesitic porphyry. The tuffs and other sediments directly derived from volcanic sources are also of this general composition. The igneous rocks occur as extrusive sheets, sills, dikes and small and moderate sized stocklike intrusives. The mineral resources of the district are not large. About 100 ounces of gold are panned annually from the rivers in the vicinity of Corozal. Gold quartz veins have been worked in the hills south of Corozal, but without success. In the barrio Pasto, southwest of Morovia, several copper prospects have been slightly explored.

Dr. **Reeds** stated that his report was one of progress; that he was prepared at this time to make only a preliminary statement concerning the fossil faunas of Porto Rico, and that his remarks this evening would be confined to the specimens which he and Mr. P. B. Hill had collected in 1915 from the younger series. A report on the fossil faunas from the older series, together with a more complete statement of the fossils from the younger series, would appear at a later date. The many hundred of specimens collected have been washed, sorted and grouped as to classes, and with the assistance of Dr. Anna I. Jonas preliminary identifications of the specimens have been made. The most common groups of fossils in the collection are Foraminifera, Echinodermata, Pelecypoda and Gastropoda. Of the forty-one species listed twenty-one are Eocene and twenty Oligocene. The Eocene forms are as follows:

Foraminifera, no species

Echinodermata—Eocene

Linthia alabamensis Clark, Midwayan.
Scutella mississippiensis Twitchell, Claibornian

Hemipata subrostratus Clark	Jacksonian
Macropneustes mortoni Conrad	
Schizaster arminger Clark	

Pelecypods—Eocene

Crasatellites aquianus Clark, Chichasawan

Lucina pandata Conrad	Claibornian
Ostrea alabamensis Lea	
Ostrea compresirostra Say	
Ostrea divaricata Lea	
Ostrea sellæformis Conrad	
Lucina whitei Clark	Jacksonian
Venus sp.	

Gastropods—Eocene

Fasciolaria hercules Whitfield	Jacksonian
Fasciolaria elevata	
Fulgar sp?	
Odostomia turricula	

Caricella subangulata Conrad	Claibornian
Cypræa lapidosa Conrad	
Pleurotomaria sp?	
Turritella mortoni Conrad	

Foraminifera—Oligocene

Cycloceypens sp? Carpenter	Vicksburgian
Nodosaria cf. bacillum de France	
Orbitoides mantelli	
Polystomella crispa	

Echinodermata—Oligocene

Amphidetus ruspatangus	Vicksburgian
Cassidulus raveneli Twitchell	
Clypeaster rogeri Morton	
Echinolampus aldrichi Twitchell	

Pelecypods—Oligocene

Cardium sp?	Vicksburgian
Cardium eversum Conrad	
Chama lyelli Dall	
Arca umbonata Lamarck	Appalachicolan
Chama chipolana Dall	
Chama tampænsis Dall	
Cardita shepardi Dall	
Cardium delphicum Dall	
Pecten chipolanus Dall	
Tellina chipolana Dall	

Gastropods—Oligocene

Ampullina fischeri Dall	Vicksburgian
Conus suridens Conrad	
Phasionella ammicoloides	
Strombus aldrichi Dall	
Strombus n. sp.	
Turritella mississippiensis Conrad	
Cerithium plectrum Dall	Appalachicolan
Murex cf. *mississippiensis* Conrad	
Turritella mediocoustriata Dall	

From this list it will be noticed that except for the echinoderm *Linthia alabamensis* Clark, which is Midwayan, basal Eocene, all of the other forms are Upper Eocene and Lower Oligocene. The Arecibo limestone, the rocks from which the specimens were collected, is thus both Upper Eocene and basal Oligocene in age. The Collazo shale which underlies the Arecibo limestone is Upper Eocene in age.

The paper was discussed by Dr. Berkey, Dr. Johnson and Mr. Hodge.

The Section then adjourned.

Chester A. Reeds,
Secretary.

BUSINESS MEETING

2 October, 1916

The Academy met at 8:20 p. m., at the American Museum of Natural History, Vice-President Ernest E. Smith presiding.

The minutes of the last meeting were read and approved.

The following candidates for Membership in the Academy, recommended by the Council, were duly elected:

Life Members

John B. Anderson
William M. Baldwin
F. Ambrose Clark
F. Gray Griswold
James H. Hyde
Francis Kleinberger
Mrs. V. Everitt Macy
J. P. Morgan
Arthur Ryle
Emil M. Sperling

Annual Active Members

Carl E. Akeley
Saverio Agnelli
C. P. Ahlstrom
Rev. Arthur H. Allen
Victor I. Altshul
Emile P. Angot
James C. Ayer
Miss Anna Baller
Charles D. Barry
Llewellyn Barry
George F. Bateman
Edwin de T. Bechtel
Frank Begrisch, Jr.
Mrs. A. Fred. Behre
William N. Best
E. R. T. Berggren
Miss Susan F. Bissell
Fred. S. Blackall
Hugo Blumenthal
A. A. Brill
Mrs. J. Hull Browning
J. A. Buda
James Byrne
E. T. Caldwell
Henry L. Calman
Rev. Thomas E. Calvert
Henry C. Carr
John J. Carty
Fred. G. Clapp
Joseph K. Choate
William Clausen
James B. Clemens
Miss Elizabeth Cogswell
Rufus Cole

David S. Collins
George W. Collins
Frederick Coykendal
W. R. Craig
George W. Crary
James W. Cromwell
R. Fulton Cutting
Benjamin G. Demarest
Rev. Herbert McK. Denslow
William P. Deppe
William T. Donnelly
Henry Doscher
Mrs. Charles Douglass
Robert Dunn Douglass
Mr. Charles Drew
William B. Dunning
William G. Eckstein
Harrington Emerson
Miss Mary Pinchot Eno
Abram Erlanger
K. George Falk
Percival Farquhar
Charles A. S. Ferguson
John A. Frothingham
Frank W. Frueauff
Albert Gallatin
Mrs. Albert Gallatin
Francis P. Garvan
Miss Annie C. Goddard
Morrill Goddard
Charles B. Going
L. Goldmerstein
W. A. Gramer
Frank L. Grant, Jr.
Simon Guggenheim
Henry Gulick
Robert Halsey
Clarence R. Halter
Mrs. Bertha Hardinge
O. A. Havill
Alfred F. Hess
Selmar Hess
George W. Hodges
Samuel Hoffman
Russell Hopkins
Miss Caroline Howe
M. D. Howell
Benjamin A. Howes
Ernest V. Hubbard
Cary T. Hutchinson
A. Fillmore Hyde
Henry James, Jr.
Reynold Janney
Mrs. Helen Hartley Jenkins
Karl Jungbluth
Ludwig Kast
William de Y. Kay
Mrs. Hamilton Fish Kean
N. C. Kingsbury
Charles M. Koplik
Adolph Lewisohn
H. T. Liang
Warfield T. Longcope
Henry Lorsch
Christopher M. Lowther
James G. Manchester
James W. Markoe
Edgar L. Marston
Walton Martin
Herbert M. Metzger
Mrs. Eugene Meyer, Jr.
Gustav M. Meyer, Jr.
A. Cressy Morrison
Dwight W. Morrow
Louis L. Mowbray
Mrs. S. Neustadt
Henry B. Newhall, Jr.
Alwin M. Pappenheimer
James C. Parrish
Mrs. Elsie Clews Parsons

George E. Perkins
Mrs. von R. Phelps
M. Bernard Philipp
Edward Plaut
Miss Florence L. Pond
Roger M. Poor
Frederick J. Powell
H. S. Putnam
Walter Rautenstrauch
Howard S. Raymond
R. M. Raymond
John King Reckendorf
Mrs. George Stuart Ring
H. B. Roelker
John Roger
Julius Rudisch
Adolphe Rusch, Jr.
Julius Sachs
Thomas B. Scott
Isaac N. Seligman
H. W. Schoemaker
Mrs. William F. Sheehan
Miss Mary Shoonmaker
William Siegel
Thomas Smidt
Mrs. R. L. Spotts
Phinehas V. Stephens
Chauncey Stillman
Marcus Stine
Willard Straight
Joseph Stroock
Moses J. Stroock
Mrs. J. Andrews Swan
Mrs. Arthur W. Swann
Jokichi Takamine
Malcolm H. Tallman
B. B. Thayer
George W. Thomson
Samuel Thorne, Jr.
J. G. Timolat
Mrs. Alice B. Tweedy
Charles A. Tyrrell
Howard S. Warren
Walter C. Webster
Harold Eastman Weeks
John E. Weeks
Richard Weil
Bernard W. Weinberger
William West, Jr.
William Y. Westervelt
L. W. Williams
Charles Wimpfheimer
Jonathan Wright
E. C. Zimmerman

The Secretary reported the following deaths:

James G. Cannon, Active Member since 1910, died 5 July, 1916,
Seth Low, Active Member since 1876, Life Member and Fellow since 1888, died 10 September, 1916.

The Secretary stated that the Council had appointed a Committee to formulate a resolution relative to the death of the Honorable Seth Low, to be spread upon the minutes of the Academy.

The Secretary reported the resignation of

William H. Bliss, Active Member since 1914.

The Academy then adjourned.

Henry E. Crampton,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

2 October, 1916

Section met at 8:30 p. m., Vice-President Ernest E. Smith presiding. The following program was presented:

Lucius P. Brown and **C. V. Ekroth**, A Promising Chart for Detecting Adulterated Samples of Milk.

Charles Baskerville, Colloids in Their Relation to Animal and Vegetable Oils.

Summary of Papers

Mr. **Brown** and Mr. **Ekroth** stated that as the result of investigations of published analyses of over 200,000 samples of milk a chart has been devised which appears to show the approximate limits of the chemical composition of normal cows' milk as concerns the fat and solids-not-fat and the inter-relation of these two. This chart should be capable of use as an indicator of adulteration in milk if the fat and total solids only are known. The inter-relation of the fat and solids-not-fat appears to indicate that almost all the milk standards as made by law in the several states of the Union, as well as that adopted by the Federal Government, are unbalanced and not based on the actual enforcement. Further, in legislating on this subject, that fat and total solids should be specified, because the figure for the total solids necessarily includes the fat and the very considerable range of limits in the fat percentage corresponding to any given figure for the solids-not-fat would allow of the abstraction of a considerable proportion of the fat without placing the milk in the adulterated class.

The accuracy of this chart has been shown by testing it against the experience of New York City for the past 10 years. A plotting of the composition of milk, as shown by analysis for this period, indicates an agreement between the percentage of fat and solids-not-fat, which is in accordance with expectations as shown by this chart.

Dr. **Baskerville** stated that animal and vegetable oils extracted from selected and perfectly clean parts are usually neutral and "sweet". Commercial exigencies result in the actual production of oils usually acid and always contaminated. It is therefore necessary to refine the oils, especially if they are to be used for edible purposes. The kinds of impurities, various but classifiable, and the favorable conditions of their production and development are given to show the principles to be considered in dealing with the problems of refining.

The impurities are, roughly stated, (1) acid in character, (2) albuminoids, (3) gums, (4) coloring matters, (5) metallic soaps, etc. The character of the crude oil depends upon not only the kind and part of the vegetable (wood, nut, seed, etc.) and animal (fish, whale, liver, etc.) used, but the quality of the raw material at the time of expressage or extraction (rusting, rotting, fermentation, sprouting, heating, etc.), the method followed, the care exercised in the process, and the conditions to which the oil is subjected prior to its refining.

The general methods developed during the past 125 years are explained. These methods usually involve more or less chemical treatment with heat and sedimentation. The latter is always time-consuming and the sediment carried with it more or less of the desired refined oil. Also oil remaining above the sediment acts as a solvent or menstruum for coloring matter and colloidal material.

The problem was to coagulate the sediment in such a manner that it might be filtered out shortly after being produced and thus remove not only the colloids, but much absorbed coloring matter, and then squeeze the mass, thereby increasing the yield of refined oil.

The problem was solved, after many thousands of trials, by adding an organic absorbent (cellulose in various forms) along with a suitable amount of caustic alkali solution, heating to the "break" and then adding a dehydrating agent (soda ash or salt cake), which would and does agglomerate the small particles and dehydrate the soap, followed by filtering while hot. The oil flows from the filter brilliant and neutral.

While the shrinkage in the process of refining usually follows the percentage of free fatty acid in the crude oil, this is not always the case. Oils very high in acid frequently do not yield to the older processes for refining, but in every case such oils have been successfully refined by the method here given.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF BIOLOGY

9 October, 1916

Section met at 8:15 P. M., Vice-President H. von W. Schulte presiding.

The following program was presented:

Herbert Lang, Faunal Relations of Central Africa.
James P. Chapin, Distribution and Migrations of Central African Birds.

Summary of Papers

Mr. **Lang** stated that the mammalian fauna of the tropical rain forests of the Congo and Amazon basins were contrasted. The more arboreal adaptation of the latter fauna and the relative lack of larger terrestrial mammals seem to suggest more inundated conditions in the Brazilian forests. The ranges of gorilla and chimpanzee were discussed. The ranges of Rhinocerotidæ, Giraffidæ, Tragulidæ and Manidæ in Africa were compared with their occurrence in the Oriental region. The connection of the African continent with Eurasia in Miocene times and the origin and center of dispersal of these forms from somewhere in central Asia was demonstrated by the Giraffidæ on a map indicating the region from which paleontological evidence is available. As a conclusion it was stated that the ranges of practically all these groups of Ethiopian mammals are chiefly dependent on the vegetation, though distinct specific forms may develop everywhere under suitable conditions. Mountains as a whole exercise very little effect, as they are too isolated in position to form effective barriers. The relative uniformity of the tropical and subtropical climate, as well as the satisfactory physiographic conditions in this region, are considered as extremely favorable for the dispersal of terrestrial Mammalia. The great West African forest, however, is an obstacle for many forms; consequently those avoiding it are found only to the northeast and south. Those species formerly believed peculiar to the South African subregion have now been recorded not only as far north as Abyssinia, but even to the northwest in Senegambia, where later *Orycteropus* and *Taurotragus* have been recorded. The intimate relationship of the fauna and flora was illustrated by a series of typical landscapes from East and West Africa. The forms peculiar to the Ethiopian region and its subregion were reviewed and shown to be especially characteristic.

Mr. **Chapin** stated that the mountains of Africa have comparatively little influence on the distribution of birds over the continent as a whole. Of far greater importance is the vegetation, and we may say that the two greatest barriers are the Desert of Sahara and the rain forest stretching from the West Coast to Uganda. Different kinds of birds have marked preference for certain plant formations; to the true forest birds the savannas and plains are a barrier, while the equatorial forest shuts off the species of open country. Thus the range of the genus *Malimbus* coincides almost exactly with the equatorial forest, while that of *Colius* covers the whole of Africa excepting the deserts and the West African forest. Many other examples could be shown. Even among water birds forest-loving forms can often be distinguished from those of the more open districts. On the other hand *Heterotrogon vittatus* is found only on the higher mountains of eastern Africa and again on Mt. Kamerun in the West Coast, and Mt. St. Isabel, on the Island of Fernando Po. In the study of bird distribution in Africa the importance of a general knowledge of the extent of forest, savanna and plains cannot be too strongly emphasized.

Our long stay in Africa gave us an exceptional opportunity to observe the migration of birds. W. L. Sclater found that of the 814 species known from South Africa 72 were migrants from Europe and Asia, while 21 were African species that come to spend the summer. In the north-eastern corner of the Congo we found about 33 species of African birds that had regular migrations and many of them were studied for three or four successive years. Since then a careful study of records with dates in books have enabled us to understand some of these movements. The Pennant-winged Nightjar (*Cosmetornis vexillarius*), breeding south of the equator, migrates northward regularly every year; whereas the Stork (*Abdimia abdimii*) nests in the north, from Nigeria to Abyssinia, and migrates to South Africa. *Batastur rufipennis,* breeding on the White Nile and Bahr-el-Ghazel, moves in the dry season up to the northern edge of the forest. This same region is visited in the dry season by a great many birds of the Sudan. Almost no forest birds are truly migratory. These few examples show that migration is characteristic of a considerable number of Central African birds, that these are movements in different directions, and that they offer an interesting subject for investigation.

The Section then adjourned. WILLIAM K. GREGORY, *Secretary.*

SECTION OF GEOLOGY AND MINERALOGY

16 OCTOBER, 1916

Section met at 8:15 P. M., Vice-President Douglas W. Johnson presiding.

The minutes of the last meeting of the Section were read and approved.

The following program was presented:

B. L. Miller, Geological Observations in the Andes of Peru and Bolivia.

Summary of Paper

Professor **Miller** stated that the South American Continent contains three great areas of highlands known as the Highlands of Guiana, the Brazilian Highlands, and the Andes Mountains. The first two correspond in a general way to the highlands of eastern Canada and the eastern United States, in that they consist largely of metamorphic rocks of Pre-cambrian or Early Paleozoic age, and represent mainly the roots of once high mountains now reduced by erosion to hills and mountains of moderate height, while the Andes are to be compared with the Cordillera of the western North America in that they are composed, for the greater part, of sedimentary rocks of Cretaceous and Tertiary age, into which have been intruded great masses of andesites, trachytes, rhyolites, and other igneous rocks, while active or recently extinct volcanoes constitute some of the greatest elevations. A more careful comparison of the Cordillera of North and South America brings out several distinctions. In the northern continent the western mountains form several discontinuous ranges which extend from east to west over a wide range of territory from central Colorado to the Pacific Ocean, while the Cordillera of South America extend uninterruptedly from Colombia to Tierra del Fuego, and are so concentrated that nowhere is the entire width more than a few hundred miles, and in many places it is scarcely more than a hundred miles from the shores of the Pacific Ocean to the eastern flank of the Andes mountains, where the great interior plains begin. Notwithstanding the compactness and continuity of the Cordillera of South America they are by no means a unit, but in the character of the rocks of which they are composed and in the uplifts to which they have been subjected they exhibit much variety and complexity. The topographic features of western South America consist of the following divisions, named in order from the Pacific Ocean eastward: (1) the Coastal Range, (2) the Longitudinal Valley, (3) the Maritime Andes or the Cordillera Occidental, (4) the Interior Plateau, Altiplanicie, or Bolivian Plateau, (5) the Eastern Andes, Cordillera Oriental, or Cordillera Real, and (6) the great Interior Plains.

All of the different ranges of the Andes are of primary importance on account of the mineral resources which they contain. In the coast ranges are numerous deposits of gold, silver and iron; in the Longitudinal Valley are the great deposits of sodium nitrate and considerable copper; in the Cordillera Occidental are rich deposits of sulphur, copper, gold, silver, vanadium and some coal; in the Interior Plateau are deposits of borax and salt; while in the Cordillera Real are numerous deposits of lime, gold, silver, antimony, and copper.

The Section then adjourned.

Chester A. Reeds,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

23 October, 1916

Section met at 8:15 p. m., in conjunction with the American Ethnological Society, Dr. A. A. Goldenweiser presiding.

The following program was presented:

P. E. Goddard, The Social Organization of the Arizona Apache.
R. H. Lowie, The Hopi Clan.

Dr. **Goddard** discussed the local bands and more particularly the social division of the White Mountain Apache, who are grouped into four exagamous, matrilineal units. Special stress was laid on the functional aspects of these clans. With the aid of diagrams an exposition was given of the Apache Kinship terminology.

Dr. **Lowie** dealt briefly with the relations of the clan to the maternal family, the phenomenon of linked clans, the descent of ceremonial offices, household groups, and the kinship terminology.

The Section then adjourned.

R. H. Lowie,
Secretary.

BUSINESS MEETING

6 November, 1916

The Academy met at 8:15 p. m., at the American Museum of Natural History, Vice-President Ernest E. Smith presiding.

The minutes of the last meeting were read and approved.

The following candidates for Active Membership in the Academy, recommended by the Council, were duly elected:

Richard J. Baker	Pliny E. Goddard
Clarence Carson	Ferdinand Howald
Everett L. De Golyer	Benjamin Lawrence

Alfred McEwen	Marion L. Thomas
Walter Mendelson	Samuel G. Tibbals
S. R. Montcalm	E. B. Treat
Arthur Mutscheller	Ludwig Vogelstein
Hideyo Noguchi	Guy B. Waite
A. E. Olmsted	H. Vincent Wallace
George B. Pegram	H. R. Wheeler
Martin De Forest Smith	Chester W. Washburne
L. A. Stoiber Rood	Pope Yeatman

Mr. John Roger, upon recommendation of the Council, was elected a Life Member.

The Acting Secretary reported the following deaths:

George Murray, Corresponding Member since 1898,

G. Langmann, Active Member and Fellow since 1899, died March, 1916.

The Council presented the following memorial to Seth Low, to be incorporated in the minutes of the Academy:

The Council and Members of the New York Academy of Sciences desire to render their tribute of honor and appreciation of the life and works of Seth Low, and especially of the services which he rendered, directly and indirectly, to the advancement of science in the city of New York and throughout the United States.

Mindful of the time, thought and liberality with which he devoted himself to the cause of good government in the city and State, to religion and philanthropy, to college and university education, few are aware of the enthusiasm, as well as wisdom, with which he guided the scientific development of Columbia University from the moment when he assumed the Presidency until the close of his tenure of office. He started with a very high ideal in the selection of the men whom he invited to the University, not only to sustain the enviable reputation which the city has gained in applied science and in certain branches of pure sciences, but also to extend the activities in pure sciences, especially along the lines of research and through the life and work of men of national and international reputation. To signalize this effort he established a special Faculty of Pure Science. In every manner, through encouragement, advice, and personal benefaction, he promoted the cause of research and publication. Taking a very broad view of the relations of the University to the community, he promoted the cause of friendly union and coöperation between the University, the New York Academy of Sciences, the American Museum of Natural History, the Botanical Garden and the

Zoölogical Park, and thus he helped to create the almost unique extension of opportunity in every field of science which New York City at present affords. His greatest desire was to see young men attracted to New York from every State in the Union to enjoy these rare opportunities, and this desire was more than fulfilled long before the close of his great and useful career. Thus we may truly say that the present union of so many scientific forces in our community is in no small degree due to the idealism, the wisdom, the energy, and the generosity of Seth Low.

The Academy then adjourned.

HENRY E. CRAMPTON,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

6 NOVEMBER, 1916

The Section met at 8:15 P. M., Vice-President Ernest E. Smith presiding.

The following program was presented:

J. M. Nelson,	CHEMICAL VALENCE.
George Falk,	THE PRODUCTION OF AN ENZYME-LIKE SUBSTANCE BY THE ACTION OF ALKALI ON PROTEIN.
George B. Pegram,	INDUCED ELECTROMOTIVE FORCE AND THE RELATIVITY THEORY.

SUMMARY OF PAPERS

Professor **Nelson** stated that simple compounds add a definite number of molecules of other simple compounds, as in ammoniates, hydrates, double and complex salts. The formation of definite addition compounds shows definite combining capacity, and therefore like valence. This molecular valence is effected by external physical conditions in the same way as ordinary atomic valence. A rise in temperature decreases the combining capacity for compounds, just as in the case of elements. The dissociation of molecular compounds obeys the mass law; thus vapor tension of hydrates and ammoniates has mass equilibrium, just as the dissociation of simple compounds. The molecular valence is a function of the two combining compounds, just as the atomic valence is a function of the two combining elements. Note the relative stability of ammonium chloride and the hydrate of hydrochloric acid, also the relative stability of cupric chloride and cupric iodide.

It has been found that in a series of addition compounds like the ammoniates of $PtCl_4$ that the diammoniate forms no ions, the triammoniate furnished one Cl-ion, the tetra-ammoniate two Cl-ions and the hexa-ammoniate four Cl-ions. By examining the composition of these various complex ions it becomes apparent that for each additional NH_3 beyond $(NH_3)_2$ one Cl is displaced. It also becomes evident that there is a constant grouping of six about the central Pt-atom. The coördination number is therefore independent of whether the groups are held by molecular or atomic valences. Many other complex addition compounds show this same coördination value of six, others show coördination number of eight. Basicity of an acid seems to be the difference between the coördination number and the atomic valence of the central atom.

Molecular valence manifests itself in addition compounds which are electrolytes as equivalent to two atomic valences. This is well illustrated in the constitution of ammonium chloride H—NH_3—Cl, in which the NH_3 enters in between the H and the Cl of the HCl. It therefore becomes evident that the molecular valence holding the ammonia and the HCl together manifests itself as equivalent to two atomic valences.

The coördination number seems to be a function of the room or space about the central atom. Thus (NH_3) $PtCl_6$ exists in two isomeric forms and the double pyramid configuration proposed by Werner accounts for the two possible isomers of a disubstituted complex of this kind.

Dr. **Falk** stated that he had studied the different ways in which the ester hydrolyzing enzyme, lipase, may be inactivated, including the action of acids, bases, neutral salts, alcohols, acetone, esters and heat. A consideration of these results led to the hypothesis that the active grouping of lipase molecule might be due to a tautomeric form of the peptide linking, which rearranged to the ordinary form on inactivation. This view was tested by means of the action of alkali on inactivated lipase material, casein, and gelatine. Lipolytically active substances were obtained from all three.

Professor **Pegram** gave a simple proof from the standpoint of the electron theory, that the seat of the E. M. F. in a unipolar induction apparatus is in the moving conductor, not in any stationary part of the circuit; the facts of unipolar induction are shown to be entirely consistent with the Einstein relativity theory.

The Section then adjourned.

V. E. Levine,
Secretary.

SECTION OF BIOLOGY

13 November, 1916

The Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The section made the following nominations for officers for 1917:

Chairman of the Section and Vice-President of the Academy, Professor H. von W. Schulte, Department of Anatomy, Columbia University.

Secretary, Professor W. K. Gregory, American Museum of Natural History.

The Secretary was instructed to transmit these nominations to the Council.

Upon request of the Secretary the Chair appointed a Committee of two, consisting of Professor Pike and the Chairman, to examine and correct the minutes of the meetings of the past year, for publication in the Records.

The following program was presented:

J. D. Kernan and **H. von W. Schulte,** On the Architecture of Two Cetacean Skulls, Xiphius and Kogia.

W. D. Matthew, Some Results of American Museum Explorations for Fossil Mammals During the Past Summer.

Summary of Paper

Dr. **Kernan** and Professor **Schulte** stated that the material for the following comparison of a skull of *Kogia* was from an individual about two-thirds grown, partially disarticulated, and a cranium of a full-term fœtus of *Ziphius cavirostris,* both in the collection of the American Museum of Natural History. In *Ziphius* the robust pterygoid was found to be composed of two synostosed and overlapping elements, one mesal and rostral, the other cuadal and lateral. The former bears the hamular process and forms the rostral half of the contour of the tubal notch. It also sends a process across the palate to articulate with the maxilla. The caudal element overlaps the rostral laterally forming the caudal half of the tubal notch and extends to the basioccipital with the otocranial flange of which it articulates. Indications of this division were found also in the adult *Ziphius,* in *Berardius* and in *Mesoplodon.* In *Kogia* only a faint furrow in the tubal notch remained in the calf. These pterygoids articulate with the alisphenoid, but in the immature skull are not synostotic with it. There was no obvious pterygoid apophysis of the greater wing. Until younger and even embryonic material is available for study the interpretation of this complex must remain problematic. In both genera a lachrymal separate from the malar was found in *Ziphius* caudal, in *Kogia* mesal to the expanded portion of the latter element. In *Kogia* the frontal process of the maxilla enters extensively into the wall of the cardinal cavity, the frontal bone itself being compressed to a narrow plate between the maxilla and supraoccipital. In this character *Kogia* departs widely from *Physeter* and the Ziphoids. *Kogia* also has no falciform process of the squamosal, in which again it differs from *Physeter* and the Ziphoids. The tympanic expands laterad into a massive process which occupied the position usually taken by the mastoid region of the periotic. In this character all the Physeterinæ agree.

The architecture of the mandible in Physeterinæ is characteristic and differs from that of the other odontocetes. The margins of the ramus are thickened and proximad are connected with a crescent of thick bone which bears the condyle. The intervening region is reduced to a papyraceous lamella. In other odontocetes, including the Ziphoids, there is a thickened axial portion of the ramus extending from the condyle to the dentigerous body of the bone. This character of the mandible and the peculiar massive pterygoid would seem to be peculiar to the Physeterinæ.

The Section then adjourned. William K. Gregory,
Secretary.

SECTION OF GEOLOGY AND MINERALOGY

20 November, 1916

Section met at 8:15 p. m., Secretary Chester A. Reeds presiding.

The minutes of the last meeting of the Section were read and approved.

The following program was presented:

E. de Martonne, The Limestone Plateaus of the Causses, Southern France.

Anna I. Jonas, Pre-Cambrian and Triassic Diabase in Eastern Pennsylvania.

A. W. Grabau, Stratigraphic Relations of the Oil-Producing to the Oil-Bearing Shales in the Paleozoic of North America; Involving a New Theory of Oil Distribution.

Summary of Papers

Professor **de Martonne** stated that the Causses are high limestone plateaus extending on the southern border of the highlands of central France. It is one of the rare examples of a natural region with a popular name, extending exactly as far as the geological formations which control its physical aspects. Nobody can fail to notice the change in topography when entering the limestone area. Water has disappeared from the surface, all valleys have become dry, many are changed into completely closed depressions called "sotch." These depressions are the only places where you can find some red soil, and, in the spring, some water; for this reason they are the only inhabited places on the plateaus. Sink holes, called "avens," are frequent; they lead to very extensive caverns, showing alternation of domes and narrow galleries, streams with cascades, lakes, splendid stalactites and stalagmites. There are not more than three valleys with water (Tarn, Jonte, Dourbie). Their depths range from 500 to 700 meters. Like the Canyon of the Colorado, they are cut in horizontal layers, showing benches in the weak beds (marls of the Lias and Middle Jurassic) and cliffs in the strong beds (more or less dolomitic limestone of the Jurassic). The cross-section and the width of the valley depends on the height at which the weak beds appear above the bottom. The total thickness of the Jurassic beds which built the Causses is much greater than the depth of the valleys. They have been dislocated by faults which can be very easily seen on the stony sides of the valleys, but do not ordinarily appear in the topography of the plateau, although the displacement can amount to over several hundred meters. The rugged but nearly level surface of the plateau may be considered as a peneplane[1] slightly modified by underground erosion and dissolution. From some well-selected points the continuity of the plateau of the Causses with the rolling surface of the highest summits of the Cévennes (Aigoual, Lozére) appears very clearly. At one point (Col de Perjuret) you can walk across a great fault separating the Jurassic area from the crystalline massif on a nearly level plain, while to the north and to the south you see subsequent valleys and cuestas developed by recent erosion. At some points on the surface of the limestone plateaus old gravels coming from crystalline massif may be found. The plateaus of the Causses seem to be a part of the highest and oldest of the three peneplane surfaces shown by Briquet and Demangeon in the central massif of France.[2] One

[1] I agree entirely with the proposal of Prof. D. W. Johnson concerning the substitution of "peneplane" for "peneplain."—E. de M.

[2] A. Demangeon, Le relief du Limousin. Ann. de Geographie, 1910, p. 120. A. Briquet, Sur la morphologie de la partie médiane et orientale du Massif Central. Ann. de Geographie, 1912, p. 30, et 122.

may wonder why only one cycle of erosion seems to have been developed in the limestone region since the late Miocene, while two are shown in the crystalline area. The cutting of the main valley must have been very rapid, while all secondary valleys became dry and many were changed into closed depressions; so that the surface of the limestone plateau suffered only slight changes by underground erosion. The greatest changes certainly did occur in the caverns, and it would be possible to trace the shifting of the base level by the study of some of them. The fact that the main valleys carry water shows that they have reached the level at which torrential circulation in the caverns is relayed by a complete filling up of all hollows, some impermeable layers preventing a deeper infiltration of water.

It may be proposed to use the word Causses in speaking of limestone plateaus similar to these described here, when the surface is dry and very few valleys carry water. One can distinguish between Low Causses, High Causses and the Alpine Causses, referring to the depth of the valleys, the surface of the plateau being more rugged on account of stronger undermining by underground erosion, when the valleys are deeper. We have described High Causses. The Dordogne and Lot cross the lower Causses of Quercy. Alpine Causses are frequent in the limestone Alps of France (Vercors) and Austria (Steinernes Meer, Todtes Gebirge, etc.).

Dr. **Jonas** stated that the region discussed occupies part of the Boyertown and Quakertown quadrangles, eastern Pennsylvania. The area lies in the Appalachian mountains, locally called the Boyertown hills, and the Piedmont plateau. The rocks of the Boyertown hills are a series of Precambrian gneisses, mainly of igneous origin. The sedimentary gneisses are remnants of the Precambrian floor into which are intruded an igneous complex of granite, diorite, and gabbro. Narrow diabase dikes cut all the Precambrian rocks. The diabase is a fine grained, dark rock with ophitic texture, composed of plagioclase, augite, pyrite and biotite. Alteration of feldspar and augite has produced a dark green schist. The rocks of the Piedmont plateau, lying southeast of the Boyertown hills, are sediments and diabasic intrusions of the Triassic age. The sediments are the Brunswick conglomerate and shale, the upper member of the Trias. Into them is intruded a diabase sheet, about 1,000 feet thick, locally called the Haycock Mountain sheet. It underlies a prominent "ridge" composed of rough hills which traverse the Quakertown quadrangle. The diabase is for the most part a light-colored, coarse-grained rock, with ophitic texture, whose constituents are feldspar (acid labradorite), augite, magnetite and biotite. Pyrite and olivine are absent. A fine-grained type occurs on the edge of the sheet. The shale adjacent to the diabase has undergone induration, crystallization, and change of color. There are developed in the round nodules of chlorite pseudomorphs after cordierite. In addition to the difference in grain between the diabase of the Haycock sheet and the dikes of the Boyertown hills, a difference owing to the greater size of the former intrusive mass, the Haycock diabase possesses certain characteristics by which it is distinguished from the diabase of the Boyertown region. The most prominent characteristic is the freshness of the constituents of the diabase of the Haycock sheet; the diabase of the Boyertown hills has undergone marked alteration by suassuritization and chloritization, which has obscured the ophitic texture and dulled the rock and changed the color. Pyrite is absent in Haycock diabase, but is abundant in the diabase of the Boyertown hills. Stratigraphic relations point to a difference in age of the two diabases. Field relations prove the Triassic age of the Haycock sheet which has invaded Upper Triassic sediments. The diabase of the Boyertown hills nowhere penetrates to a horizon younger than the Precambrian. Therefore the alteration prevalent in the diabase of the Boyertown hills may be explained by their Precambrian age and the greater metamorphism they have undergone.

Professor **Grabau** stated that the three important oil-bearing formations which he has studied in detail are the Trenton limestone, the Onondaga (Corniferous) limestone, and the Upper Devonic oil sands of Pennsylvania. In all cases it is shown that these formations grade laterally into black shales of sapropeltic origin, these shales being the source of the oil. Lateral migration along the bedding planes has resulted in the accumulation of the oil in the more porous limestones or sandstones in which they are found today. The beds which have produced the oils are the Utica shale (in its broadest sense), the Marcellus, and the Ohio shales. The relation of the Utica-Trenton and of the Ohio-Portage relation is an interfingering one. The lower two shales are sapropelites; the upper more nearly a humulith, though having some sapropelitic admixtures. The significance of this relationship in the determination of oil-bearing horizons is apparent.

The Section then adjourned.

Chester A. Reeds,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

27 November, 1916

The Section met in conjunction with the New York Branch of the American Psychological Association at Columbia University.

The following program was presented:

L. S. Hollingworth, Echolalia in Idiots: Its Meaning for Modern Theories of Imitation.

G. C. Myers, Shrinking of Images.

J. C. Bell, A Comparison of the Binet-Simon Tests of Intelligence and the Squire Graded Mental Tests.

Summary of Papers

Dr. **Hollingworth** stated that echolalia (which is a curious tendency found in aments and in certain insane patients to echo or repeat whatever is said to them or in their hearing) has occasionally been described in the literature of pathological psychology, notably by Barr. The present paper describes three cases of echolalia in idiots, one case being a child of five years, the second a child of eleven years, and the third a man of about thirty years. These patients showed marked ability and tendency to repeat automatically whatever was said to them, revealing no understanding of the question-response situation. Instead of replying to questions, they simply repeat them mechanically. Such cases are of great interest in connection with modern controversies about the nature of imitation in man. Professor Thorndike has recently called into question former ideas about imitation, and has debated the propriety of its inclusion, as a general tendency, among the instinctive tendencies of man. Professor Montague has made persuasive objection to Professor Thorndike's discussion and final conclusion, holding that the potency of behavior to produce similar behavior in witnessing human beings cannot be satisfactorily explained on the ground of a few specific inherited tendencies plus the laws of habit formation in general. Does the behavior of our three idiots furnish any new light to the controversy? It would be desirable to have much more information about the development and modifiability of the echolalia which they showed. However, it is very difficult to see how their tendency to duplicate behavior experienced is to be explained except on the basis of instinctive imitation. The patients were idiots, incapable of adapting themselves independently to even very simple situations, or of understanding the significance of what was said to them. Their "echoing" would seem to be inexplicable by the laws of habit formation in general, or on the basis of any specific inherited tendencies. If we explain the behavior of such patients as due to an instinctive tendency to imitate, shall we assume that they suffer from some characteristic lesion, which sets them apart as a separate species? Or does their reaction indicate the presence of an instinct which is an element in the original nature of man, and is distributed according to the curves of probability?

Professor **Myers** stated that eight students of Columbia University, under certain standardized conditions, cut threads which represented one of two dimensions of some familiar object, voluntarily selected, which could not be seen during the experiment. These threads were placed between the pages of a magazine where the date and introspections were recorded. One subject first imaged tactually, then visually; the rest, as a rule, imaged visually. Some imaged once a day, some twice and some three times, until they each had about fifty records. Later these threads were measured in millimeters by the writer.

Four other subjects thus imaged ten familiar objects successively for six continuous hours, of whom two later selected an arbitrary thread length and repeatedly cut threads for one hour to equal the memory length of that thread. Five more did the same for one-half hour. Twelve subjects, for one hour each, also imaged an object which had been presented before the experiment began. Its dimensions were 228 by 44 mm. These dimensions, which were voluntarily selected, ranged from 34 inches to about one inch.

Curves were presented of individuals and of the group of twelve. Although there were considerable individual differences there were no exceptions to the rule that the general trend of the curve was downward. Most resembled the learning curve. The curves for length and width were remarkably parallel. The sizes of the object imaged, as a rule, were greatly underestimated. This was only a preliminary report.

Mr. **Bell** stated that the Binet tests have been criticized because of the trivial nature of some of the tests, the arrangement of the tests, and the mental age of the pupil. The Squire tests were constructed with greater regard to psychological analysis, but have been used as a graded series only by Mrs. Squire herself. It was proposed to investigate the relative values of the two series of tests for school purposes. Both were given to twenty-three elementary pupils in grades four to seven, inclusive; three from each half grade except the high seventh, where only two were available. No retarded pupils were included. By the Binet tests the mental age of the pupils ranged from one year below their chronological age to four years above. To reduce the results of the Squire tests to a single expression for each pupil the highest score in each test was placed equal to 100, the lowest equal to 0, and the other scores were reduced to corresponding values. The results for each individual in the eighteen tests were then averaged for a final score. The Pearson coefficient of correlation between these scores and the Binet mental ages was .70. The Binet tests were found superior, because they could be given in one-fourth the time required for the Squire tests, because the interest of the pupil was maintained at a higher pitch and because the results were more easily interpreted.

The Section then adjourned. R. H. LOWIE,
Secretary.

BUSINESS MEETING

18 DECEMBER, 1916

The Academy met at 8:15 P. M., at the American Museum of Natural History, Secretary V. E. Levine, Section of Astronomy, Physics and Chemistry, presiding.

The minutes of the last meeting were read and approved.

The following candidates for Active Membership in the Academy, recommended by the Council, were duly elected:

H. E. Anthony
Charles D. Atkins
Morton L. Byers
Georges Crozel
Otto H. Klein
John De Witt Sterry

The Secretary reported the following death:

Prof. F. J. H. Merrill, Active Member since 1886, Life Member since 1915, died 1 December, 1916.

The Academy then adjourned. HENRY E. CRAMPTON,
Acting Recording Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

4 DECEMBER, 1916

Section met at 8:25 P. M., Secretary V. E. Levine presiding.

The following program was presented:

Victor E. Levine, CHEMICAL REDUCTIONS IN THE LIVING ORGANISM.

Clement S. Brainin, COMPARATIVE INTENSITIES OF X-RAYS FROM VARIOUS METALS.

SUMMARY OF PAPER

Dr. **Brainin** stated that X-radiation is a by-product of the collision between atoms and fast-moving electrons. X-rays are electromagnetic ether waves like light waves, differing from them only in wave-length and frequency, the wave-length of light being about .00005 cm. and that of X-rays of the order of .00000001 cm.

We distinguish two classes of X-rays:

1. Characteristic or homogeneous rays, which are emitted by a metal when hit by electrons of proper velocity for that particular metal, which in turn is determined only by the atomic weight (or number) of the metal. These rays are all of the same wave-length.

2. General radiation, which consists of rays of many different lengths, like a spectrum from an incandescent solid. The voltage impressed on the tube determines both the intensity of emission of any particular wave-length and the length of the shortest wave present in the X-ray spectrum. This can be determined from the formula (potential) (electronic charge) = (Planck's constant) (frequency of wave).

In these experiments the anode was a hexagon, on each side of which a different metal was attached, and which could be magnetically rotated to bring the different metals under the electron stream. The X-rays passed out of the tube through a mica window .001 cm. thick into an ionization chamber, which completely absorbed the rays for all potentials used. The intensity was measured by the usual ionization method.

The following table shows metals used and critical voltages for producing characteristic rays of each:

Platinum	(atomic	weight,	195),	about	100,000	volts.
Tungsten	"	"	184	"	95,000	"
Silver	"	"	108	"	25,500	"
Molybdenum	"	"	96	"	19,500	"
Copper	"	"	64	"	12,000	"
Cobalt	"	"	59	"	10,000	"

The following table shows relative emissivity of these metals at different voltages in descending order:

5,700	8,200	10,000	10,700	12,800	14,200	17,500 up to 40,000
Pt }	Pt	Pt	Pt	Pt	Pt	Pt
Ag }	Ag	Ag	Ag }	W	W	W
W	W	W	W }	Ag	Co	Co
Mo	Mo	Mo	Co	Co	Ag	Cu
Cu	Cu	Co	Mo	Mo	Cu	Ag
Co	Co	Cu	Cu	Cu	Mo	Mo

V. E. LEVINE,
Secretary.

SECTION OF BIOLOGY

11 December, 1916

Section met at 8:15 p. m., Vice-President H. von W. Schulte presiding.

The following program was presented:

H. D. Senior, The Development of the External Iliac Artery in Man.

Halsey J. Bagg, The Genetics of Certain Types of Animal Behavior.

John T. Nichols, Development and Distribution of Fresh-water Fishes in Africa.

Summary of Papers

Professor **Senior** stated that in man and pig the femoral artery is not developed directly from the hypogastric, as described by Hochstetter in cat and rabbit,[1] but that the femoral and inferior epigastric arise from a common stem (the external iliac), which antedates them both considerably in development.

The external iliac arises from the lateral side of the hypogastric and is quite independent of the segmental arterial system. It takes a longitudinal course, crossing medial to the root of the obturator nerve in the cephalic direction. During the considerable period of development which precedes the origin of the femoral and inferior epigastric from it, its walls become progressively thickened by condensation of the adjacent mesenchyme.

The femoral artery, when it has once appeared, very rapidly extends to the popliteal fossa and there taps the ischiadic. The external iliac, on the contrary, scarcely alters in appearance between the human stages of 8.5 and 12 mm., and between the stages in pig of 10 and 12 mm. or somewhat later.

Reconstructions are shown of this vessel in human embryos of 8.5 and 12 mm. (crown-rump measurement), and in pig embryo of 12 mm. (greatest total length). In none of these stages is the femoral present. In a reconstruction of a human embryo of 13.6 (greatest total length) the femoral and inferior epigastric arteries are well developed, and the

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[1] Ueber die ursprüngliche Hauptschlagader der hinteren Gliedmasse des Menschen und der Saügerthiere, u. s. w., Morpholog. Jahrb., Bd. 16, S. 300, 1890.

former has already tapped the ischiadic in the popliteal fossa. Whether the femoral arise before the inferior epigastric from the external iliac, or *vice versa*, or whether they arise simultaneously, has not been ascertained from lack of suitable material. Should the femoral arise prior to the inferior epigastric, it would by no means invalidate the fact that the external iliac is not merely the root of the femoral; but a separate vessel having a developmental history quite peculiar to itself. The external iliac is the second branch (in time of development) of the hypogastric, the ischiadic (inferior gluteal) being the first. Before the femoral arises from the external iliac there are four branches of the hypogastric, viz., ischiadic, external iliac, internal pudenal, and superior gluteal.

Mr. **Bagg** stated that the plan of the experiment is to measure individual differences in behavior in various strains of mice; to determine the extent to which an animal which departs from the average in one direction will depart in others; to measure the resemblance in families and in lines of descent, and to determine the degree to which kinds of conduct can be established in family lines by selection. Results have been so far obtained for over two hundred mice that were tested in two types of mazes. Striking individual differences have been noted for various tasks, and an apparent resemblance between mice belonging to the same litter was found to be nearly twice as great as between unrelated individuals. There appears to be a considerable difference among strains of mice, and the sex differences, if any, are slight.

Eight generations of mice have been so far obtained, and the genetics of the problem has resolved itself into a study of the offspring obtained from mating animals that are quick to learn with those slow to learn, those that are quick with quick ones, and slow with slow ones. The effects of inbreeding and outbreeding are also being tested.

Mr. **Nichols** stated that the comparative development of the groups of Ostariophysous fishes in Africa and related families indicates that the Mormyrids are a remnant of an earlier ichthyfauna, and that of the more modern groups the Catfishes came first, then the Characinæ; the invasion of Carps is very recent and still in progress.

In comparing the condition found in South America the absence of Carps is accounted for by recent isolation of that continent by sea, the development of the Gymarchids by absence of similar Mormyrids, and the diversified development of Catfishes by supposing them to have been the first fresh-water family in the field.

The Section then adjourned.

William K. Gregory,
Secretary.

ANNUAL MEETING

28 December, 1916

The Academy met in Annual Meeting on Monday, 18 December, 1916, at the Hotel Manhattan, at the close of the Annual Dinner, President Michael I. Pupin presiding.

The minutes of the last Annual Meeting, 20 December, 1915, were read and approved.

President Dr. Michael I. Pupin delivered the annual address, entitled "The University and Industrial Research."

Reports were presented by the Corresponding Secretary, the Acting Recording Secretary, the Librarian, and the Acting Editor, all of which were received and ordered placed on file.

The Treasurer's report showed a net cash balance of $1,770.58 on hand 30 November, 1916. On motion, this report was received and referred to the Finance Committee for auditing.

The Acting Secretary presented an informal report of the activities of the Committees on the Centennial Celebration. It was stated that the membership of the Academy was to be increased to one thousand, that a history of the work during the past century was to be prepared, that meetings and a general exhibition showing the progress of science would be held during the second week in May, 1917, and that a fund of one hundred thousand dollars was being raised for the support of scientific activities, like the Porto Rico Survey. Contributions of $5,000 each by Professor N. L. Britton and President M. I. Pupin had already been promised.

The following members of the Academy were elected Fellows, the Secretary being authorized to cast a single affirmative ballot for the list as presented:

Carl E. Akeley, American Museum of Natural History,
H. E. Anthony, American Museum of Natural History,
John J. Carty, 15 Dey Street, City,
Mary C. Dickerson, American Museum of Natural History,
Pliny E. Goddard, American Museum of Natural History,
Charles B. Going, 140 Nassau Street, City,
Otto H. Klein, 127 Worth Street, City,
Hideyo Noguchi, Rockefeller Institute,
George B. Pegram, Columbia University,
Walter Rautenstrauch, Columbia University,
Phinehas V. Stephens, 1258 Morris Avenue, City.

The Academy then proceeded to election of officers for 1917. The ballots prepared by the Council in accordance with the By-Laws were distributed. On motion, the Secretary was authorized to cast a single affirmative ballot for the list of nominees as presented:

President: MICHAEL IDVORSKY PUPIN.

Vice-Presidents: DOUGLAS W. JOHNSON (Section of Geology and Mineralogy), HERMANN VON W. SCHULTE (Section of Biology), ERNEST E. SMITH (Section of Astronomy, Physics and Chemistry), J. McKEAN CATTELL (Section of Anthropology and Psychology).

Corresponding Secretary: HENRY E. CRAMPTON.

Treasurer: HENRY J. COCHRAN.

Librarian: RALPH W. TOWER.

Editor: RALPH W. TOWER.

Councilors (to serve three years): JOHN H. BARNHART, GEORGE B. PEGRAM.

Finance Committee: JOHN TATLOCK, BASHFORD DEAN, FREDERIC S. LEE.

On motion, the appointing of a Recording Secretary was referred to the Council for action. Subsequently, by the authority of the Executive Committee, Ralph W. Tower was elected to this office.

A report on the work of the Porto Rico Survey was read by Professor N. L. Britton, Chairman of the Porto Rico Committee. It was voted that this report be received and placed on file.

The following illustrated accounts of recent scientific activities were then presented before the Academy:

PROF. CHARLES P. BERKEY, "The Geological History of Porto Rico."

DR. HERBERT SPINDEN, "Ethnic Relations Between Porto Rico and Venezuela."

MR. C. WILLIAM BEEBE, "Zoölogical Studies of British Guiana."

The Academy then adjourned.

HENRY E. CRAMPTON,
Acting Recording Secretary.

REPORT OF THE CORRESPONDING SECRETARY

We have lost by death during the past year the following Honorary Members:

George W. Hill, elected 1898,

Sir Henry Enfield Roscoe, elected 1887, died 18 December, 1915,

and one Corresponding Member:

George Murray, elected 1898.

There are at present upon the rolls 40 Honorary Members and 111 Corresponding Members.

Respectfully submitted,

HENRY E. CRAMPTON,
Corresponding Secretary.

REPORT OF THE RECORDING SECRETARY

During the year 1916 the Academy held 8 business meetings and 28 sectional meetings, at which 73 stated papers were presented, as follows:

Section of Astronomy, Physics and Chemistry, 15 papers; Section of Biology, 21 papers; Section of Geology and Mineralogy, 17 papers; Section of Anthropology and Psychology, 20 papers.

At the present time the membership of the Academy is 687, which includes 666[1] Active Members (of whom 23 are Associate Members, 132[2] Fellows, 108 Life Members and 11 Patrons) and 21 Non-Resident Members. There have been 6 deaths during the year, 13 resignations have become effective and one name has been dropped from the roll. Two names have been transferred to Non-Resident Membership. Two hundred sixteen new members have been elected during the year and eleven have commuted their annual dues by a single payment of $100 each. One name has been transferred to the Life Membership list on account of the payment of Annual Dues for a period of twenty-five years. One Associate Member has taken up Active Membership. As the membership of the Academy a year ago was 491, there has been a net gain of 196 during the year of 1916. Record is made with regret of the loss by death of the following Active Members:

James G. Cannon, Active Member since 1910,
G. Langman, Active Member since 1899,
Hon. Seth Low, Active Member since 1876,
F. J. H. Merrill, Active Member since 1886,
Nathaniel C. Nash, Active Member since 1910,
Ignaz Matausch, Active Member since 1914.

Respectfully submitted,

HENRY E. CRAMPTON,
Acting Recording Secretary.

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[1] Including 22 members elect and one Associate made Active to begin 1917.

[2] To this number must be added the eleven Fellows elected at the Annual Meeting, 18 December, 1916.

REPORT OF THE LIBRARIAN

It is doubtful if in the history of the New York Academy of Sciences the library has been so much used by scientists and naturalists in the vicinity as during the year just past. The files, in conjunction with those of the American Museum of Natural History, now form a remarkably complete library in the subject of Natural History, as well as in the proceedings of the Learned Societies of the world.

The uncertainty of the foreign mails and the disturbed political situation in Europe have caused an almost complete cessation of exchanges with that part of the world; on the other hand, opportunity has thus been afforded for promoting a more intimate affiliation with our sister societies in South America.

Respectfully submitted, RALPH W. TOWER,
Librarian.

REPORT OF THE EDITOR

The parts of the Annals which have been published this year are as follows:

VOLUME XXV

	Pages
L. E. W. Benedict—A Study of Bagobo Ceremonial, Magic and Myth...	1–308

VOLUME XXVI

E. O. Hovey—Records of Meetings of the Academy..................	395–462
Membership of the Academy..........................	463–474
Index	475–486

VOLUME XXVII

T. Barbour—Some Remarks upon Matthew's "Climate and Evolution." with Supplemental Note by W. D. Matthew...........	1–15
J. A. Allen—An Extinct Octodont from the Island of Porto Rico.......	17–22
W. D. Matthew—New Sirenian from the Tertiary of Porto Rico.......	23–29
C. C. Mook—A Study of the Morrison Formation.....................	31–38
H. E. Anthony—Preliminary Report of Fossil Mammals from Porto Rico..	39–191

There are likewise in press two papers, one by Warren S. Smith, entitled "Physiography of the Skykomish Basin, Washington," and the other by J. Alden Mason, entitled "Tepecano, a Piman Language of Western Mexico." The Publication Committee has accepted for publication a paper by H. E. Armstrong, entitled "Operating Features of the Audion."

Respectfully submitted,

HENRY E. CRAMPTON,
Acting Editor.

REPORT OF THE TREASURER

MEMBERSHIP

Paid up, Active Members (174 of these were elected after 1 May and paid $5 for 1916)	304
Paid up, Associate Members	18
Delinquent Active and Associate Members	37
Life Members and Patrons	119
Members elect (not yet paid dues)	23
	666

RECEIPTS

December 1, 1915—November 30, 1916

Cash on hand, December 1, 1915		$488.17
Life Membership Fees		1,100.00
Income from investments:		
Interest on mortgages on New York real estate	$851.82	
Interest on railroad and other bonds	1,350.00	
		2,201.82
Interest on bank balances		30.62
Active membership dues, 1908	$10.00	
" " " 1909	10.00	
" " " 1910	10.00	
" " " 1911	10.00	
" " " 1912	20.00	
" " " 1913	20.00	
" " " 1914	50.00	
" " " 1915	215.00	
" " " 1916	3,810.00	
" " " 1917	195.00	
		4,350.00
Associate membership dues, 1915	6.00	
" " " 1916	54.00	
		60.00
Sale of publications		209.33
Contribution to cost of publication		250.00
Subscription to annual dinner (1915)		302.50
Porto Rico Survey (subscription)		1,000.00
Porto Rico Government (refund of advances made on account of field expenses)		1,600.74
Cash on note in bank		1,000.00
Total		$12,593.18

DISBURSEMENTS

December 1, 1915—November 30, 1916

Publications on account of Annals	$1,887.63
Publication of *Bulletin*	680.55

Recording Secretary's expenses	293.53
Recording Secretary's and Editor's allowance	1,375.00
Esther Herrman Research Fund (grants)	550.00
John Strong Newberry Fund (grants)	100.00
General expenses	105.45
Annual meeting and dinner (1915)	401.60
Porto Rico Survey (advances on field expenses)	3,383.80
Section of Geology and Mineralogy	28.90
Centennial Celebration—Membership Campaign	1,002.69
Payment of note in bank	1,000.00
Interest on note in bank	13.45
Cash on hand	1,770.58
Total	$12,593.18

BALANCE SHEET, NOVEMBER 30, 1916

Investments (cost)	$42,332.92	Permanent Fund	$24,754.66
Cash on hand	1,770.58	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 Audubon Fund	885.08
		Income Newberry Fund	194.49
		Income Esther Herrman Fund	1,769.27
	$44,103.50		$44,103.50

PROPERTY		Cost
Lampe Mortgage	at 5 per cent.	$12,000.00
Deane-Brennan Mortgage	at 5 per cent.	4,036.67
4 Detroit City Gas Co. bonds	at 5 per cent.	4,000.00
3 Grand Rapids Gas Light Co. bonds	at 5 per cent.	2,880.00
20 Madison Gas and Electric Co. bonds	at 6 per cent.	10,400.00
1 Binghamton Gas and Electric Co. bond	at 5 per cent.	995.00
1 Quebec-Jacques Cartier Electric Co. bond	at 5 per cent.	965.50
1 San Antonio Traction Co. bond	at 5 per cent.	487.50
1 San Antonio Gas and Electric Co. bond	at 5 per cent.	487.50
5 U. S. Steel Corporation bonds	at 5 per cent.	5,081.25
Participation bond of Lawyers' Mortgage Co	at 5 per cent.	1,000.00
		$42,332.92

Respectfully submitted,

HENRY J. COCHRAN,
Treasurer.

15 FEBRUARY, 1917.

Examined and found to be correct.

JOHN TATLOCK,
BASHFORD DEAN,
Auditing Committee.

REPORT OF THE PORTO RICO COMMITTEE

Under the direction of the Committee of the Academy appointed in 1913 work on the scientific survey of Porto Rico has been continued during the year in many branches of the subject, both in the field and in the laboratory and in the preparation of preliminary papers and of the final reports.

Areal geological surveys have been carried out by Mr. Bela Hubbard in the northwestern part of the island, which included, among other points of special interest, the study of a stratum at the base of the Tertiary series of the island previously detected by Dr. C. A. Reeds, containing large numbers of fossil plants; this discovery, being the first indication of the occurrence of Tertiary fossil plants in the West Indies, is of great interest, and the study of the fossil leaves may give us our first knowledge of the ancestors of some tropical plants; the collections have been referred to Dr. Arthur Hollick for study. Dr. Charles R. Fettke carried out an areal survey of the southwestern districts, which included a detailed study of the large areas of eruptive rocks in that part of the island. Mr. A. K. Lobeck studied the physiographic geology of the whole island. The reports of Mr. Douglas R. Semmes on the areal survey of the San Juan District, and that of Mr. Edwin T. Hodge on the Coamo-Guayama district, based on their field work of the previous season, are completed and ready for publication. Progress has also been made in the study of the palæontological collections made by the several field expeditions, and data relative to economic geology are being assembled.

In botany the most important field work accomplished was the expedition of Professor H. H. Whetzel, of Cornell University, and Dr. E. W. Olive, of the Brooklyn Botanic Garden, for the study and collection of parasitic fungi, which was prolific in results, their collections including several hundred specimens, which are under investigation by a number of different experts. The Uredineæ (rusts) of this large collection, taken together with the specimens of this family previously collected, have enabled Professor J. C. Arthur to prepare a noteworthy paper on this group for early publication. Professor F. L. Stevens has published during the year his monograph on the Porto Rican species of the genus *Meliola*. Additional general collections by Mr. John A. Stevenson, of the Insular Experiment Station at Rio Piedras, have added to our knowledge of a number of plants. Work on the manuscript for the final reports has been continued by several botanists, and a large number of specimens have been returned to Porto Rico and are deposited in the herbarium of the Insular Experiment Station.

In zoölogy study has been continued by several investigators from the collections already made; they plan coördinating the results already reached, and thus ascertaining where the gaps exist which need to be filled by further field operations. A large collection of mollusks has been returned to Porto Rico for installation in the new museum room in the Carnegie Library Building at San Juan. Very important preliminary papers on the fossil mammals obtained by our collectors from the floors of caves have been published in the Annals of the Academy by Dr. J. A. Allen, Dr. W. D. Matthew and Mr. H. E. Anthony, including the description of an apparently new family, a new genus, and several new species, results which were entirely unexpected. The study of the rich entomological collections, by several experts, has yielded scientific information of high importance and several preliminary papers are in course of preparation.

The study of the anthropological collections made during 1915 has yielded proofs of the use of some of the caves as burial places by the aborigines, and the great quantities of one of the few species of extinct mammals found in the caves indicate this animal was extensively used by them for food. Further progress was also made on the survey of the ancient settlement of Capa, the most important of all archæological localities thus far examined in Porto Rico. The reduction of the anthropometric data obtained has been continued; these are as yet incomplete, requiring additional field observation; their completion would give us information regarding the differences in the rate of physiological and mental development of children here and in the temperate zone, which would be of highly educational importance in arranging school curriculums in Porto Rico. The voluminous folk-lore records accumulated in 1915 by Mr. J. A. Mason have been referred to Professor Aurelio M. Espinosa, of Leland Stanford University, who reports that this material is more extensive than all hitherto published Spanish folk-lore literature, and that it gives us for the first time the means of a careful comparison of Spanish and other European folk-lore. Dr. Herbert J. Spinden prosecuted ethnological observations in several parts of the island during the season, and made extensive additional collections.

At the request of the Committee, the Council of the Academy has set aside volumes of the Annals, commencing with Volume 33, for the final Porto Rican reports to be published in the sequence: (1) Geology and Invertebrate Palæontology, (2) Botany, (3) Zoölogy and Vertebrate

Palæontology, (4) Anthropology, and, pursuant to another request of the Committee, the Council voted to reserve as much of the income of the Herrman Fund as may be practicable for the next few years for the use of the Committee in preparing final reports through the aid of students not immediately connected with the coöperating institutions. Further field work will be mainly dependent upon additional appropriations being made by the Porto Rico Government.

The Committee gratefully acknowledges the continued financial aid generously given by ex-President Emerson McMillin and the coöperation of the many experts from other institutions.

Respectfully submitted,

N. L. Britton,
Chairman of the Committee.

December 18, 1916.

MEMBERSHIP OF THE

NEW YORK ACADEMY OF SCIENCES

HONORARY MEMBERS

31 December, 1916

Elected.

1912. Frank D. Adams, Montreal, Canada.
1889. Charles Barrois, Lille, France.
1907. William Bateson, Cambridge, England.
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.
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.
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.
1898. Fridtjof Nansen, Christiania, Norway.
1908. Wilhelm Ostwald, Gross-Bothen, Germany.
1898. Albrecht Penck, Berlin, Germany.
1898. Wilhelm Pfeffer, Leipzig, Germany.
1900. Edward Charles Pickering, Cambridge, Mass.
1911. Edward Bagnall Poulton, Oxford, England.
1913. Sir David Prain, Kew, England.
1899. Lord Rayleigh, Witham, Essex, England.

ELECTED.

1898. HANS H. REUSCH, Christiania, Norway.
1912. SHO WATASÉ, Tokyo, Japan.
1904. KARL VON DEN STEINEN, Berlin, Germany.
1896. JOSEPH JOHN THOMSON, Cambridge, England.
1900. EDWARD BURNETT TAYLOR, Oxford, England.
1904. HUGO DE VRIES, Amsterdam, Holland.
1907. JAMES WARD, Cambridge, England.
1904. WILHELM WUNDT, Leipzig, Germany.

CORRESPONDING MEMBERS

31 DECEMBER, 1916

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.
1868. M. C. COOKE, London, England.
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.

ELECTED.

1894. RUTHVEN DEANE, Chicago, Ill.
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.
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, B. W. I.
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.
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.
1892. J. DE MENDIZÁBAL-TAMBORREL, Mexico City, Mexico.
1874. CLINTON HART MERRIAM, Washington, D. C.
1898. MANSFIELD MERRIAM, South Bethlehem, Pa.

ELECTED.

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.
——. 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.
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.

ELECTED.

1897. STUART WELLER, Chicago, Ill.
1874. I. C. WHITE, Morgantown, W. Va.
1898. HENRY SHALER WILLIAMS, Ithaca, N. Y.
1866. HORATIO C. WOOD, Philadelphia, Pa.
1899. A. SMITH WOODWARD, London, Eng.
1876. HARRY CRÈCY YARROW, Washington, D. C.

ACTIVE MEMBERS

1916

Fellowship is indicated by an asterisk (*) before the name; Life Membership, by a dagger (†); Patronship, by a section mark (§).

*Abbe, Dr. Cleveland
Abercrombie, David T.
†Adams, Edward D.
*Adams, L. A.
Agnelli, Saverio, M.D.
Ahlstrom, C. F.
*Akeley, Carl E.
†Alexander, Chas. B.
Allen, Arthur Huntington
*†Allen, J. A., Ph.D.
*†Allis, Edward Phelps, Jr., Ph.D.
Altshul, Victor I.
*Ames, Oakes
Anderson, A. A.
Anderson, A. J. C.
†Anderson, John B.
*†Andrews, Roy C.
Angot, Emile P.
*Anthony, H. E.
†Anthony, R. A.
Archer-Shee, Mrs. M.
Arctowski, Dr. Henryk
Arend, Francis J.
†Armour, Allison V.
†Armstrong, S. T., M.D.
Arnold, James Loring
Ashby, George E.
Atkins, Charles D.
Avery, Samuel P.
Ayer, James C., M.D.
†Bailey, James M.
Baird, Charles
Baker, Hugh Potter
Baker, Richard J.
†Baldwin, William M.
Baller, Miss Anna R.
†*Barnhart, John Hendley
Barron, George D.
Barry, Charles D.
Barry, Llewellyn
*Baskerville, Prof. Charles
Bateman, George F.
Baugh, Miss M. L.
Bechtel, Edwin de Turck
*†Beck, Fanning C. T.
*Beebe, C. William
Begrisch, Frank, Jr.
Behre, Mrs. A. Frederick
Behrend, Otto F., Ph.D.
Beller, A.

Beller, William F.
Berggren, E. R. T.
†Bergstresser, Charles M.
*Berkey, Charles P., Ph.D.
Bernard, Pierre A.
Bernstein, S. S.
Best, William Newton
Betts, Samuel R.
van Beuren, F. T.
Bigelow, William S.
Bijur, Moses
†Billings, Miss Elizabeth
Bird, Henry
Bishop, Heber R.
Bishop, Miss Mary C.
Bissell, Miss Susan F.
Blackall, Frederick S.
Blake, Mrs. Catherine K.
Blake, Joseph A., Jr.
*†Bliss, Prof. Charles B.
†Blumenthal, George
Blumenthal, Hugo
*Boas, Prof. Franz
Böhler, Richard F.
†Bourn, W. B.
*Bowman, Prof. Isaiah[1]
Boyd, James
†Brackenridge, George W.
Brill, A. A., M.D.
Brinsmade, Charles Lyman
*Bristol, Prof. Charles L.
Bristol, Jno. I. D.
*§Britton, Prof. N. L., Ph.D.
Brown, Edwin H.
Brown, Lucius P.
Brown, T. C.
*Brownell, Silas B., LL.D.
Browning, Mrs. J. Hull
Buda, J. A., M.D.
Burr, Prof. Freeman F.
Burr, Winthrop
*Bush, Wendell T.
Byers, Morton L.
Byrne, James
*Byrnes, Miss Esther F., Ph.D.
Caldwell, E. T.
Calman, Henry L.
Calvert, Rev. Thomas Elliot
Camp, Frederick A.
*Campbell, Prof. William, Ph.D.
*Campbell, Prof. William M.
Carlebach, Walter Maxwell
Carr, Henry Clay
*Carty, John J.
*§Casey, Col. T. L., U. S. A.
Cassard, William J.
Cassebeer, H. A., Jr.
*†Cattell, Prof. J. McKeen, Ph.D.
*†Chandler, Prof. C. F., Ph.D.
§Chapin, Chester W.
*Chapman, Frank M.
†Chaves, José E.
*Cheesman, Timothy M., M.D.
Choate, Joseph K.
Chubb, Percy
Clapp, Frederick G.
†Clark, F. Ambrose
Clark, Howard L.
Clarkson, Banyer
Clausen, William
Clayburgh, A.
Clemens, James B., M.D.
Clendenin, Wm. W.
†Clyde, Wm. P.
†Cochran, Henry J.
Cogswell, Elizabeth N.
Cohn, Julius M.
Cole, Rufus

[1] Member elect.

Colfelt, Mrs. Rebecca McM.
Collier, Robert J.
Collins, David S.
Collins, George W., M.D.
†Collord, George W.
Combe, Mrs. William
†Constant, S. Victor
de Coppet, E. J.
Corning, Christopher R.
Coykendal, Frederick
Craig, W. R.
*Crampton, Prof. Henry E., Ph.D.
†Crane, Zenas
Crary, George W., M.D.
Cromwell, James W.
Crozel, Georges
*Curtis, Carlton C.
Curtis, G. Warrington
Cutting, R. Fulton
*Dahlgren, B. E., D.M.D.
Davies, J. Clarence
Davis, David T.
*†Davis, William T.
*†Dean, Prof. Bashford, Ph.D.
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