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THE AGATE HILLS

History of Paleontological Excavations, 1904 - 1925

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Property of
Agate Fossil Beds National Monument

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TO TED AND MARIAN GALUSHA,

THIS WORK IS DEDICATED

ACKNOWLEDGMENTS

I owe a significant debt to many individuals who gave their time and energy to help with this project. A historical survey often involves hours of patient effort by archivists who somehow manage to discover that rare item necessary to complete a critical aspect of the study. This work would not have been finished without the unheralded dedication of many such people, some whose names I never learned.

In the field, I was fortunate to have the support of the National Park Service staff at Agate Fossil Beds National Monument. Superintendent A.J. Banta and Chief Ranger John Rapier helped in innumerable ways throughout our survey, often providing critical assistance in permit and excavation work. Rangers William Taylor and Robert Todd encouraged our efforts, and took an active interest in the project. Logistical support and encouragement provided by Regional Chief Scientist Gary Larson and his associates in the Omaha headquarters of the Midwest Region, National Park Service, simplified our work and are gratefully acknowledged. The project has benefited from a strong cooperative effort between National Park Service and University of Nebraska personnel.

At the University of Nebraska State Museum, registrar and archivist Rebecca Monke aided in bringing together correspondence and archival materials of E.H. Barbour. Joshua Kaufman prepared important fossils, worked with me in field survey and excavation, and discussed many aspects of the study. His companionship in the field made the work truly enjoyable. Mary Rebone, Robert Skolnick, and John Morgenson participated in several phases of the project, and provided invaluable assistance in the field.

At the Carnegie Museum, Pittsburgh, Betty Hill and Mary Dawson generously provided access to their paleontological archives, aided me in locating O.A. Peterson's journals and correspondence, and gave excessively of their time to help with the project. Mary, Betty, and Dave Berman made my stay in Pittsburgh a very pleasant experience.

At the American Museum, Dick Tedford and Ruth Sternfeld guided me through the well organized archives of the Department of Vertebrate Paleontology, and gave much time in locating previously unknown correspondence and maps of the American Museum excavations from 1911 through 1923.

At Yale University, John Ostrom permitted access to all early records of Yale work at Agate under R.S. Lull. Mary Ann Turner spent considerable time bringing these records together, and pointed out journals and correpondence that I otherwise would have missed.

At Amherst College, I benefited from the help and counsel of Margery and Walter Coombs. Their efforts have considerably improved the status of the fossil mammal collection of F.B. Loomis. Without their spirited responsible actions on the part of paleontologists, this Early Miocene collection would probably not exist as a nationally significant research tool.

At the University of Florida and University of Michigan, S.D. Webb and Philip Gingerich made Agate fossils and records freely available to me during brief visits.

At the Field Museum, Chicago, William Turnbull located Agate documents and fossils, and provided gracious hospitality. He also permitted me to examine the newly discovered field diaries of Albert Thomson, donated to the Field Museum in 1982 by the late Mrs. Robert E. Gregg of Boulder, Colorado. Mrs. Gregg was the daughter of the paleontologist Paul Miller, and the niece of Albert Thomson. The Thomson diaries, as a brief perusal of this report will indicate, were the most important source of information on the American Museum excavations at Agate from 1911 to 1923. These volumes increased several fold our knowledge of the Agate excavations in the early part of this century, and preserve a daily account of Thomson's activities during the Agate work.

At the South Dakota School of Mines, Phil Bjork and Jim Martin answered many queries about their Agate collections and allowed me to examine important specimens.

My thanks to Don Baird, Princeton University, for helping me with the work of W.J. Sinclair at Agate in 1914, and informing me of the Agate materials maintained at Princeton.

I thank Morris Skinner for bringing to my notice the map of the Agate quarries sketched by Harold Cook probably about 1911. This map gives Cook's personal letter designations of the various Agate quarries and as such is an important historical addition to the records of Agate excavations.

Finally, an important acknowledgment is reserved for those paleontologists who took time to record their observations, map their discoveries, set down the insignificant as well as the momentarily significant, because without such carefully kept field records, future investigations built on earlier studies are necessarily limited in what they can achieve.

PREFACE

The great bone bed at Agate has caught the imagination and attention of scientists and the public since the significance of the deposit was first recognized by the paleontologist Olaf Peterson in 1904. August 1984 is the 80th anniversary of this discovery, and 1985 will mark an equally significant event: the centennial of James Cook's initial discovery of bones at the Agate hills near his ranch in the valley of the Niobrara River in 1885.

The period of greatest scientific activity at Agate occurred during the two decades that followed Peterson's recognition of the importance of the site. From 1904 to 1925, North American museums and universities competed for Agate's fossil resources. In this study, I have tried to capture both politics and scientific procedures in summarizing the history of the excavations in the Agate hills. In so doing, we see early 20th century paleontology in whole cloth, as it was actually practiced. I offer no apology in adopting this approach, since I find as much fascination and significance in the history of the science as in its findings. Fortunately, my professional goals coincided with the needs of the National Park Service, who required identification and a history of work at the various quarries in the main hills to manage the fossil resources at Agate.

After 1925, excavations in the Agate hills never attained the magnitude or intensity of the early years. Some believed that the important information had been gleaned from the Agate quarries, and it was best to maintain the sites as a scientific storehouse of good exhibit materials, to be tapped when needed by museums wishing to mount a rhinoceros skeleton or two. Others saw value in preserving the quarries as a national resource, whereby both the known and well recognized aspects of the bone bed, as well as its as-yet-undiscovered potential, would be actively conserved. In 1965, the Agate Fossil Beds National Monument was created by act of Congress.

Despite the vigorous activity at Agate during the early 20th century, the data collected in the various quarries was never brought together and systematically evaluated. The competitive attitude among the several field parties precluded a useful synthesis of scientific results. Field data were accumulated by different methods, and recorded in different styles. Exchange of information took place, but only as a courtesy, and never with a summary of the paleontology of all sites in mind. Hypotheses explaining the origin of the great bone bed were proposed, but none proceeded from careful evaluation of observations of the bones, the enclosing sediments, and the local and regional geological context in which they were found.

Thus there was a need to summarize what was known about Agate, prior to the initiation of new excavations. Naturally, this proved a wise approach, for much emerged in the historical survey of the quarries that can guide future planning and interpretation. My own views on the origin of the deposit have changed since I first began work on the Agate sites, and have led me to see where new excavation would be most valuable in answering key questions about the origin of the bone bed. We have already a much clearer insight into Agate's place in the regional geologic setting -- the ancient environments of 20 million years ago are today much better understood. Although I cannot yet write that only one hypothesis is needed to explain the origin and setting of the Agate bone bed, I can say that the presently known evidence gathered from archives and our recent field studies allows only a few well defined scenarios. From among these, we can more objectively choose in the next few years as research continues.

What have we learned about the setting and origin of the Agate bone bed? The regional geologic setting of the site is perhaps best known, based on a decade of study of the Cenozoic rocks of Sioux County by University of Nebraska field parties (1973-1983). The bone bed occurs in a sandy ephemeral stream channel setting. The quarries tap a bone accumulation that came to rest in the base of such a stream channel. These ephemeral streams traversed flat interchannel plains that extended westward to the Rocky Mountain uplifts. A semiarid, seasonally wet, continental climate with warm winters is most plausible, possibly developed in the rain shadow of the mountains.

Turning to the local setting, the sediments that enclose the bones are similar in pattern in all the quarries in the main Agate hills, indicating that the burial event responsible for preservation of the bone bed was common to all sites, and probably of short duration. But here similarity ends, for the most interesting and previously unappreciated result of this study was the discovery that the nature of the bone bed differs somewhat among the various quarries. Some quarries are dominated by scattered, fragmented, and abraded bones, the residue of gradual skeletal attrition through normal environmental agencies (climatic weathering of carcasses, scavenging and trampling of skeletons, stream abrasion and fragmentation). The bone bed in such quarries is not the result of a single sudden mass death event, followed by rapid burial of the carcasses, but reflects a more gradual temporally extended process of skeletal disintegration. Some time has elapsed between death and final burial. On the other hand, the major Agate quarry (Southwest Excavation) has produced numerous disarticulated but largely intact, unbroken, and unabraded bones of both chalicothere and rhinoceros, many without attritional damage, and some still grouped together in individual associations. In this case, the process of skeletal destruction has made little progress prior to sediment burial of these bones. Large intact blocks of such bones encased in the original sediment taken from this quarry are commonly exhibited in major North American museums and universities, and have been thought typical of the bone bed (see p. 138f., Figs. 3.61, 3.62). Other blocks from this same quarry, such as the superb slab on exhibit at the Carnegie Museum, are made up of bones that have been scavenged, abraded, and broken prior to burial. Such differences in the nature of the bone bed reflect slightly different histories for these areas in the quarry. In June-July 1984, test pits placed by our field party in the Southwest Excavation revealed at least two square meters of the quarry floor in which skeletal disintegration was advanced, and scavenging of many bones was evident. Here in the largest of the Agate quarries, a complex history of skeletal processing is indicated, and additional excavation will be necessary to understand the pattern of the deposit.

Why such differences occur between the parts of the bone bed is not clear. Several hypotheses can account for these differences, and in this report, an initial attempt is made to explore them. At the present time, the explanation in conformity with the earlier excavations and our own 1984 field work envisions the bone bed in the main hills as the product of multiple death events, in a sense the sum of many small catastrophes that befell populations of rhinoceros, chalicothere, and entelodont in the sandy wide shallow ephemeral stream valley where the bone bed accumulated over time. No single death event need be greater in magnitude than present day mass mortalities that deplete living ungulate populations in semiarid grassland environments today, such as the Serengeti ecosystem of East Africa. In the Serengeti and its neighboring environs, ungulates die in significant numbers (tens to hundreds) in mass drownings at river fords, in lake crossings, and through lack of food, drought and disease. In such a seasonal climate, rainfall occurring at certain times of the year tranports and concentrates dried carcasses, individual bones, and partially fragmented skeletons in the watercourses. Semiarid grassland plains subject to seasonal sudden intense rainfall often are characterized by major streamfloods capable of transport and deposition of 1-2 feet of fine sandy sediment. Such a flash flood could have initiated the final burial event at Agate. This flood entombed (1) a basal lag gravel of worn and fragmented bones and teeth mixed with rounded Harrison Formation sand pebbles -- this lag gravel formed over a period of months to years; (2) rhinoceros, entelodont, and chalicothere remains at various stages of skeletal disintegration in the ephemeral stream valley and its tributaries when engulfed by the flood event -- these carcasses were probably the result of individual and mass deaths that took place periodically over no more than about ten years, based on the observed degree of bone weathering; (3) individuals drowned in the flood event itself, represented by associated skeletons and the few well articulated specimens in the bone bed. New evidence from the Agate sites is necessary to confirm or modify this scenario as work continues in the quarries.

This survey has also resulted in the first mapping of the quarries (Map A) since the termination of excavations in the main hills in 1965. Map A (in pocket on back cover) shows the names I have adopted in this report for the various Agate quarries in the main hills. The quarries on Carnegie Hill have been given many names over the years; in Appendix A (p. 158f.) these names are synonymized and grouped under the site designations used on Map A. Four topographic elevations were the focus of all early excavations in the main Agate hills in section 10, T.28N, R.55W: these are named on Map A, from north to south, North Ridge, University Hill, Carnegie Hill, and Beardog Hill.

The aim of this historical survey has been not only to bring together the widely dispersed information on the Agate hills, a task that has long needed attention, but also to begin to clarify the picture created by this diverse data base by initiation of new research into the Agate fossils and field sites. Much work needs to be done, but with the start of new excavations at Agate in 1981, the necessary step was taken to develop an improved perspective on this major North American fossil site. New insights at Agate must rest ultimately on renewed field exploration. Techniques change and improve with time in any science. To achieve progress, the earlier results must be blended with new observations. Furthermore, an historical perspective, employed in this survey of Agate's excavations, demonstrates better than any other example the dependence of one generation of paleontologists upon the next, and illustrates the necessity for detail and care in recording field observations in the science of paleontology. With this end in mind, I dedicate this study to a paleontologist who exemplified these professional standards, and who taught many of us through his own example -- Ted Galusha.

University of Nebraska — Robert Hunt, Jr.
July 1984

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ABBREVIATIONS

ACM,	Amherst College Museum, Amherst
AMNH,	American Museum of Natural History, New York
CM,	Carnegie Museum of Natural History, Pittsburgh
FMNH,	Field Museum of Natural History, Chicago
UNSM,	University of Nebraska State Museum, Lincoln
USNM,	National Museum of Natural History, Smithsonian Institution, Washington
YPM,	Peabody Museum, Yale University, New Haven

1. DISCOVERY OF THE AGATE FOSSIL BEDS

1.1. O. A. Peterson and the Carnegie Museum

Olaf Peterson (1865-1933), who came from Sweden to the United States when 17 years of age, became aware of vertebrate fossils from his brother-in-law, J. B. Hatcher. In 1888, as a young man, he was hired by Hatcher to assist in collecting fossils in Nebraska and Wyoming for O. C. Marsh of Yale University. Peterson was employed both in the field and in the New Haven laboratory of Marsh from 1888 to 1891. From 1891 to 1896 Peterson worked for the American Museum in New York, eventually leaving this institution to join his brother-in-law on the Princeton expeditions to Patagonia in 1896 and 1898. In 1900, in part due to Hatcher's legendary success in South America, both Peterson and Hatcher left Princeton and joined the Carnegie Museum in Pittsburgh.

It was during his tenure with the Carnegie Museum that Peterson had his major impact on North American paleontology. His research on the terrestrial Cenozoic rocks and fossil mammals of Sioux County, northwest Nebraska, can be regarded as his best work, for he not only collected most of the fossils, but also published a number of major monographs on the fauna. Much of this is still useful today. He began his Sioux County explorations in 1901, continued them in 1902, and in 1904, despite adverse circumstances, recognized the importance of the Agate bone bed.

In Sioux County (Fig. 1.1), Peterson first worked the Oligocene White River badlands north of the Pine Ridge escarpment. These barren sculptured hills so near the escarpment still produce mammalian fossils in quantity. Today the escarpment defines the northern limit of a great remnant tableland, now bisected by the Platte River, but at one time in the late Cenozoic extending without interruption from northern Nebraska to northern Colorado, a north-south distance of over 150 miles. The present tableland is the dissected vestige of a thick wedge of Cenozoic terrestrial sediments, its western margin in contact with the Rocky Mountain ranges and its eastern edge thinning toward the midcontinent. Extensive badland rock outcrops, representing the oldest part of this wedge, are prominently exposed along the southern and northern bounding escarpments of the tableland. Field collectors like Hatcher and Peterson, early in this century, were involved in geographically wide-ranging searches for exhibit quality fossils, and commonly sought out such promising badland areas where the probability of success was high. In 1901 the White River badlands of Nebraska and South Dakota were known to produce mammalian fossils in abundance, and the Pine Ridge escarpment was a logical place for Peterson to begin his search.

The geologist N. H. Darton in 1899 recognized two stratigraphic divisions within the Pine Ridge escarpment, named by him the White River Formation and Arikaree Formation. The upper part of the escarpment is formed by Arikaree rocks; the lower part of the escarpment and the flatland extending north from it are White River beds. From as early as 1886 until 1895, Hatcher had traveled through this area, and worked the deposits for fossils, focusing primarily on the White River terrain.

The extraordinary fossil potential of northwest Nebraska was evident to Hatcher, and in 1901 he assigned Peterson the task of amassing a collection from the Sioux County Cenozoic sequence. This seems to have been stimulated by Hatcher's own work in the Sioux County deposits in 1900: with his assistant, W. H. Utterback, Hatcher spent three or four weeks in the Arikaree near Harrison, Nebraska, and then moved on to the more productive White River beds. Hatcher's effort of 1900 represents the first record of prolonged work by the Carnegie Museum in Sioux County Arikaree rocks (earlier work by Hatcher for other institutions was focused on the White River, especially on the great titanotheres found in these beds). Only a very small sample of fossil mammals was collected by the two men. However, Hatcher's initial foray into the Arikaree beds in 1900 was the first step of a long productive journey for the Carnegie Museum field men that would reach its scientific climax with Peterson's discovery of the Agate bone bed in Arikaree sediments in 1904.

Peterson's first documented work in the Sioux County Arikaree beds took place in May 1901 when, camped to the north of Pine Ridge on Prairie Dog Creek, he traveled south to Harrison for mail and supplies, and looked over the "Daimonelix beds" (gray Arikaree sandstones with large helical rodent burrows) on his journey to town. Forced to remain in town due to rain, he wrote on May 25, "Went afoot to the south of Harrison; found Daimonelix beds exposed on all elevated points. Found fragments of a rodent skull ...." He continued to collect in both the Arikaree and White River of Sioux County during the summer months, but focused on the White River during May, June and July. In August, he moved south into the Niobrara Canyon, and began his important collection of mammalian fossils from the Arikaree cliffs on the south side of the canyon immediately east of the Nebraska-Wyoming state boundary. He worked this area (which was to become the type locality of his "Upper Harrison" beds) during August and September, returning to Pittsburgh on October 4.

In 1902, Peterson again returned to Sioux County, undoubtedly because of the rich collection of fossils that he had found the previous year. Locating near the old postoffice of Adelia, he worked the White River beds until late in August, then entered Wyoming to explore the dinosaur-bearing rocks of the Lance Creek region north of the Hartville Uplift. In 1903, Peterson did not go into the field but remained in the laboratory at the Carnegie Museum, working on fossil mammals found by him during the previous two field seasons.

In 1904, Peterson returned to the field with Hatcher's strong

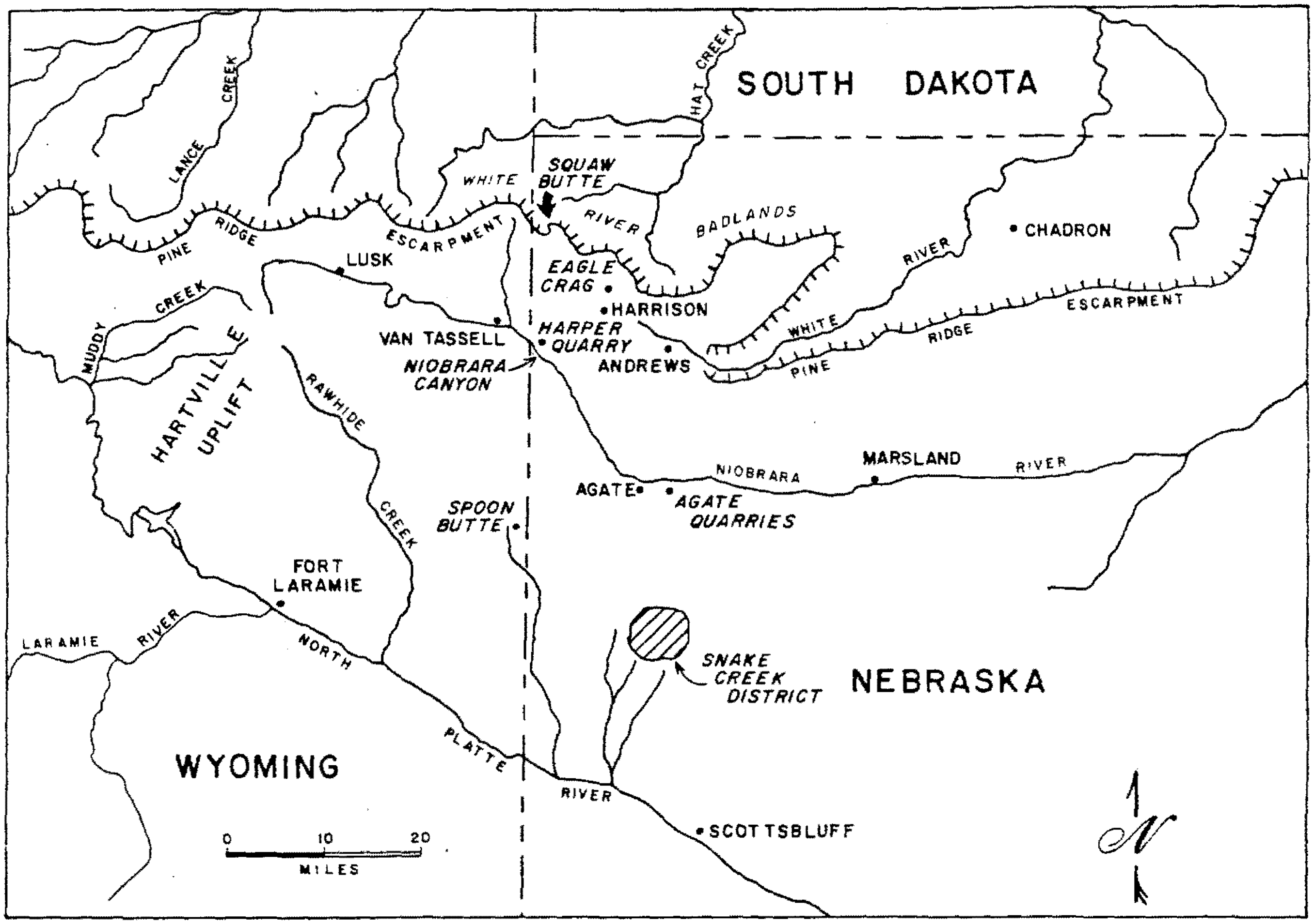


Fig. 1.1. Map of the Agate region, showing the principal geographic features and localities mentioned in the text. The area was the focus of early field studies by E.H. Barbour, O.A. Peterson, J.B. Hatcher, and Albert Thomson at the turn of the century. These paleontologists entered the region by railroad, then traveled through the area by horse and wagon until the advent of the automobile. The principal points where the field parties left the railline and outfitted were Harrison and Andrews, Nebraska, and Van Tassell and Lusk, Wyoming. Thus, many of the most important early localities are near these towns. Much early exploration for fossil mammals was focused in the White River badlands and along the Pine Ridge escarpment where prominent exposures of mid-Cenozoic rocks produce numerous fossils.

encouragement to continue his Sioux County explorations. Two unusually important discoveries befell Peterson: (1) the explanation of the origin of the enigmatic helical fossils called devil's corkscrews or 'Daimonelices'; (2) the finding of the Agate bone bed.

At the start of field work in late May and June 1904, Peterson explored the lower Arikaree rocks, trying to find fossils in the Gering sandstones at the base of the Pine Ridge escarpment, but with little luck. He did obtain some bones from the "upper Monroe Creek beds", at a higher level in the Arikaree. On June 6, Hatcher advised, "While it would have been gratifying had you been able to report more satisfactory finds from the Gering sandstones, yet this was to be expected; however, if after a week spent in those beds you meet with no better success should think it would be best to devote your attention to either the underlying or overlying deposits." It was the overlying rocks that Peterson attacked with characteristic vigor, working the upper Arikaree on the tableland's surface near the postoffice of Van Tassell, Wyoming.

Van Tassell lies near the Nebraska state line in the valley of the Niobrara River. In this area, the river and its local tributary streams dissect the surface of the tableland, producing numerous bare fossiliferous outcrops of the Arikaree. A visit to this locality in July 1904 marked the beginning of Peterson's interest and extended work on the 'devil's corkscrews'; his notes include numerous sketches of these bizarre Arikaree fossils. The corkscrews were helical spirals of finely layered gray sandstone, often encased in a silicified rind of fossil plant roots, some penetrating the interior. Sometimes found in groups, each corkscrew was spaced a specific distance from its neighbors. They were first noticed in 1891 by E. H. Barbour, a Nebraska paleontologist, who argued that they were giant plant fossils. Barbour resolutely maintained this view at the time of Peterson's Sioux County explorations.

On July 4, 1904, Peterson found and studied a large grouping of corkscrews along the south side of the Niobrara River in Wyoming opposite the mouth of Van Tassell Creek. His notes reflect his excitement at what he found: "I had not remained very long in this locality before I became convinced of the origin of the Daemonhelix. I found remains of rodents, not only one case but 6 or 7 cases, and in two instances I found nearly the complete skeletons lay in the weathered out inside of the corkscrew! Not once did I find the rodent remains attached to the outside surface of the burrow, or, corkscrew, but always on the weathered out inside of the casts. The fact that rodent remains are thus found in these casts of burrows or Cork Screws and seldom ever found in the soft sandstone separate from the burrows is alone evidence of their true origin." From this time, Peterson never doubted that the origin of these 'corkscrews' was attributable to the rodents found in them.

In 1904, Peterson left some field notes of his Sioux County work, including a geologic cross-section of the tableland from Pine Ridge as far south as Spoon Butte (Fig. 1.2), and excellent notes and diagrams of the corkscrews near Van Tassell. But notes on the discovery at Agate, written in the field at the time, have not been located. This seems to have resulted from a personal tragedy that befell Peterson in early July 1904, for after that time he apparently made no detailed field notes.

Unknown to Peterson at the time of his corkscrew discovery, his colleague Hatcher had contracted typhoid fever in Pittsburgh in late June and quickly became gravely ill. On June 30th, unaware of Hatcher's condition, Peterson penned a routine letter from the field in Harrison, Nebraska, discussing expenses, weather, and fossils found, stating: "I am now about through along the Pine Ridge and expect to move camp in a day or so, down towards Vantassle (sic) where I expect to spend a week or so in the Harrison beds before we start for the Reservation."

On July 1, W. J. Holland, the controversial director of the Carnegie Museum, had written Peterson a troubling letter:

> "My Dear Mr. Peterson;-
> I dare say that you have been advised ere this of the fact that Mr. Hatcher is ill with typhoid fever. He was taken to the hospital a few days ago, and, I understand, is very sick, though not according to accounts in imminent danger.... Meanwhile, while he is ill and unable to attend to his work, you had better communicate with me directly in reference to any matters that require attention .... I trust that you will report to me as to your movements, so that we may keep in touch with you."

Probably weakened by years of sustained overexertion in research and fieldwork, Hatcher failed to recover, and died on July 3rd at the age of 42. On July 4th, Peterson learned of Hatcher's death, and the next day wrote Holland of his plan to return to the east:

> "My Dear Dr. Holland:
> Last night late a telegram was brought out to my camp with the very sad news that Mr. Hatcher is dead. I just got in. Have wired Mrs. Hatcher [Peterson's sister] ....
> [There] will now necessarily be changes which will affect every one concerned in the department. I have accordingly decided to close up my work here as soon as I can and come back to Pittsburgh. I wish to be there, if for nothing else to try to console and help Mrs. Hatcher as much as I can. Should it become advisable I could come out later in the season, or, the work could be resumed again next spring.
> I have met with very good success the last 2 weeks and was just on the point of writing Hatcher some very important

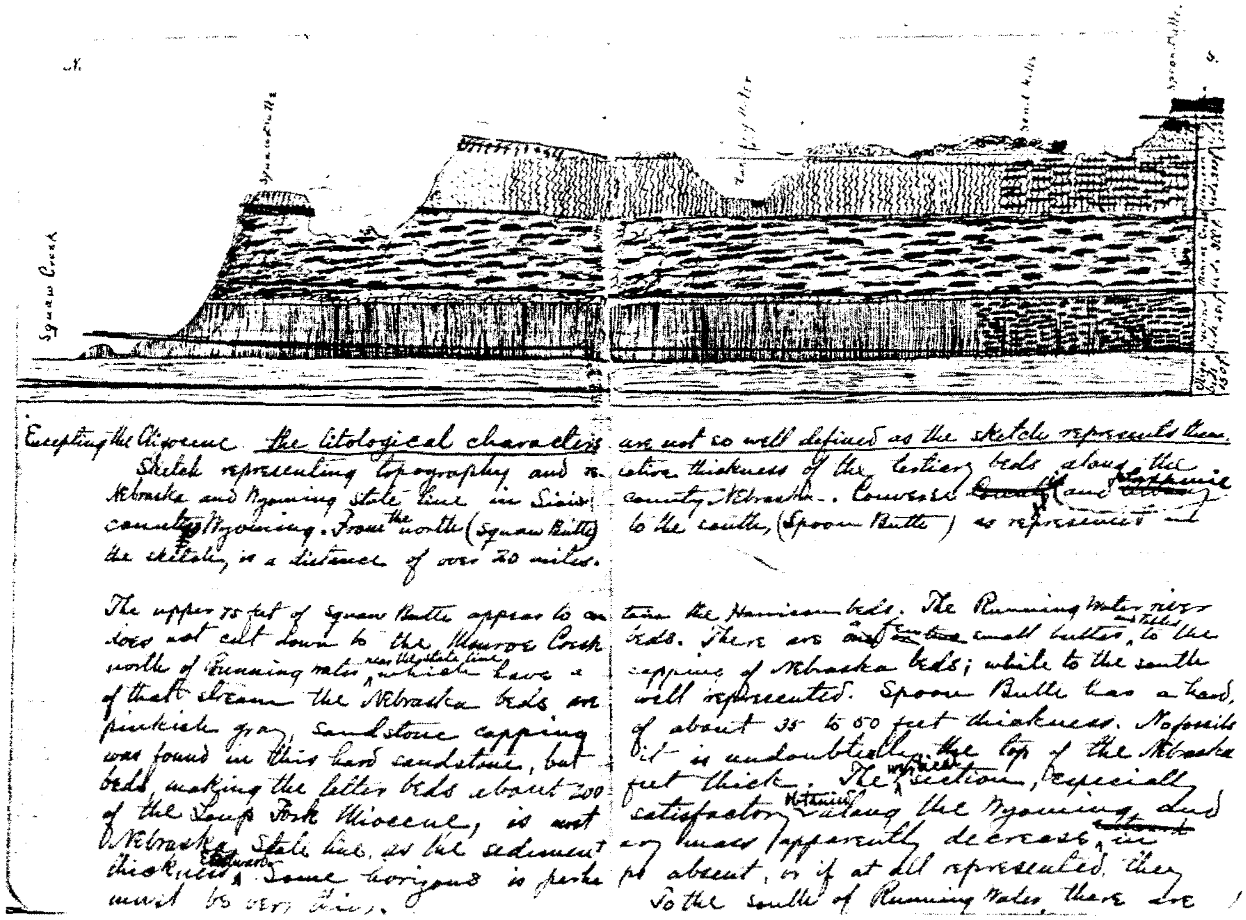


Fig. 1.2. Geological cross-section of the Hartville Table, from the Pine Ridge escarpment (Squaw Butte) to Spoon Butte, from 1904 field notes of O.A. Peterson, who indicated that the Arikaree tableland was made up of a sequence of superposed tabular rock units (Gering, Monroe Creek, Harrison, "Nebraska" [=Upper Harrison]). Line of section (north to south) nearly parallels Wyoming-Nebraska state boundary. The Niobrara River (Runningwater of Peterson) has cut the Niobrara Canyon at the center of the cross-section. In 1904, the faults that occur in the region (see Fig. 2.2) were not known to Peterson.

discoveries which I have made the last day or two when I got the message from Mrs. Hatcher."

On July 8, Holland replied:

"My Dear Mr. Peterson;-

I received your letter this morning in which you stated that you had decided to cease work and come home in order to at least comfort your good sister, Mrs. Hatcher. Mr. Mellor and I were at Mr. Hatcher's residence this morning, at Mrs. Hatcher's request, and we talked over the matter carefully, and it seemed to us that in view of all the circumstances it was scarcely wise for you to stop work where you are, especially in view of the fact that you tell us you have made important discoveries, and come back here.... Mr. Mellor and I, as well as your sister, think the best thing you can do under the circumstances is to remain where you are and carry on the work that you are doing with energy.... I telegraphed you today informing you of the substance of this decision, using the words - 'Have consulted Mrs. Hatcher; your return won't help; go on with work; am writing fully.' In case at a later date it should be judged necessary that you should return we can arrange for it, but I doubt very much whether it would be wise for you to pull up stakes and come back now. That would sacrifice the good results which in your letter you say you are just on the eve of achieving. Utterback reports that thus far he has accomplished nothing throughout the season, and I should regret very much to have to report to Mr. Carnegie that neither party had succeeded in accomplishing anything this summer ....

Until a successor to Prof. Hatcher is secured I shall act as the head of the Section of Paleontology in the Museum, and shall expect you to report to me everything just as you were in the habit of doing to Mr. Hatcher, and to keep me fully advised of all your movements and of your necessities."

On July 11, Peterson responded to Holland's incredible letter in a matter-of-fact tone, but his true reaction was distilled in letters to H. F. Osborn at the American Museum, and to Charles Schuchert at the National Museum, later in July:

"My Dear Dr. Holland:

In reply would say that the discovery I have made (determining what the Devils CorkScrews are) can not be much improved on. I will however continue to get a few more specimens, and may perhaps go up on the Sioux Indian Reservation a short while before coming back. In the meantime, I wish you would kindly tell Mr. Douglass to get together all literature on Daemonhelix [sic] and send to me. I would like to write a preliminary note to Science before other parties do it for me, and I think the credit should go to the discoverer and our institution."

On July 25, Peterson was more candid with his old employer Osborn:

"My Dear Prof. Osborn:
It is truly a pity that after Hatcher worked as hard as he did to get to where he could begin to reap some genuine satisfaction and pleasure of his many years of hard toiling in the field, he should be taken away. It is not only a great loss to his poor wife and children but as you have truly said a loss to science as well.
With considerable pleasure and satisfaction not to say proudness I watched his steady onward march to distinction, well knowing that he now occupied a place where he could with undividing energy devote his whole ambition to his most cherished work and I looked forward to years of pleasant cooperation with him.
Returning from an extensive horseback trip the fourth of July I was rejoicing to myself over the good news I had to tell Hatcher of my discovery that day (the discovery of what the Daemonelix really are) when I met one of my men - I sent both of them [Olcott and Dodd] to town the third to spend the fourth of July. As soon as I recognized him I was under the influence of a peculiar sensation, and after reading the yellow slip he handed me I felt dizzy.
I wanted to go back immediately but Dr. Holland insisted on my continuing the work. That he was now in full charge of that dept. and for me to report to him until such time as he could get the proper party in Hatcher's place.
As a matter of fact I have no heart to do work as I did formerly. Dr. Holland is no doubt favorably disposed toward me but I know that he is not capable of the sympathy a field man craves in connection with paleontology. Not knowing what is going on or what changes are taking place in the museum I am naturally on the alert for another place as I may on my return find that a change will be necessary."

Earlier, on July 18, Peterson had written Charles Schuchert in Washington at the National Museum:

"My Dear Mr. Schuchert:
Knowing there is a vacancy in the National Museum I respectfully ask you what the position is?... I trust you know me and what I have been doing for the past 16 years to present my case to Dr. Merrill....
I know nothing as yet of what changes may take place in Pittsburgh since Hatcher's death and naturally [am] on the alert should things turn uncongenially there tc necessitate making a change."

On July 22, Schuchert replied encouragingly to Peterson:

"Dear Mr. Peterson:
Since Hatcher's lamented death I saw Hermann at New York

and I spoke of the vacancy in this museum in the vertebrate division. As you know we had hopes of securing Hatcher but his death upset all our plans. Telling these things to Hermann he urged our securing your services in the strongest terms which I have done with Dr. Merrill. If you care to make a change I can say that Dr. Merrill will be greatly pleased to consider you as a candidate."

Against this background of events, Peterson prepared to travel to Agate to look over the region in the vicinity of the James Cook ranch. His emotional state could hardly have been less conducive to careful observation of the area, and the detailed recording of his finds. On July 28th, the eve of his departure for Agate, he wrote Holland a terse note:

"Dear Dr. Holland:
Since about the 18th of June we have had very good success to within the last few days. We leave this place tomorrow on a short trip to a new locality. I expect we will be gone some 2 weeks perhaps longer, if we meet with any success. In the meantime I would wish and expect 1st, a guarantee to the Depot Agent for the shipment of fossils. 2nd, advice as to the disposal of the outfit. You will please direct letter to Harrison Nebraska as that will be our next P.O. address."

Peterson must have reached Agate during the first days of August. At that time, when Harold Cook had just shown him the fossils in the Agate hills, several letters arrived at Agate for Peterson, one from Schuchert providing him further encouragement in his attempt at the National Museum position, and the following letter from Holland which could have done little to ease Peterson's state of mind:

Aug. 1, 1904

"My Dear Mr. Peterson,
As I see by the account that you send me that you have only $1.59 on hand, I herewith send you a check for $100, on account of field expenses, which you will kindly receipt.
You ask me to furnish a guarantee to the depot agent at Harrison, Nebraska, for the shipment of fossils. I do not understand what you mean by a guarantee unless it be a letter from me giving assurance that the freight on the material will be paid upon delivery. I enclose a letter which I suppose will cover the purpose. If it is not what is wanted, please let me know, and tell me what the station agent requires.
You ask me for directions as to the disposal of the outfit. I wish to say in this connection that I would like to have full information from you as to what you have in the way of an outfit and its condition. You must not imagine because Mr. Hatcher is dead that the work of the Department of Paleontology at this Museum is going to end or that we shall

> not have need of your services and of the services of the entire staff. While we deplore Mr. Hatcher's death most deeply, you must understand that the work of this Museum goes on forever. I wish you to stay in the field and gather all the good material that you possibly can. I know you to be an eminently successful collector, and I do not think that an early return on account of Mr. Hatcher's death will mend matters at all. The more you collect this summer the better it will be both for the institution and for your own reputation. If you have good prospects and there is material that can be acquired that is needed in the Museum, get it. I prefer to have you stay in the field as long as there is any chance to do good work. I know that Professor Hatcher's death has necessarily to some extent unsettled your mind, but you need have no discouragement on that score. As long as I am satisfied with you and well pleased it makes no difference who is Professor Hatcher's successor. You are sure of your position. I am, as you are aware, the man who is to be satisfied....
>
> In the letter you wrote me preceding your last you state you have made some discoveries upon the origin of Daemonelix, and express a wish to prepare an article for Science upon the same. I desire to say that I shall be very pleased to have you write an article for Science, and of course you understand, under our rules and regulations all publications in relation to the expeditions conducted and in relation to the material collected on such expeditions must be submitted to the Director. You would also possibly be glad to have the benefit of my editorial supervision. If you will write your article and send the same to me I will see that it is transmitted in proper form to the editor of Science."

This was the last letter received in the field by Peterson, and it is not difficult to imagine his state of mind during the work at Agate.

Peterson left no field notes on Agate. He reports the details of his discovery of the quarries in his publications (Peterson, 1906, 1909; Holland and Peterson, 1914). Hatcher's death and the conflict with Holland, as they probably contributed to Peterson's deteriorating mental and physical condition, must in part be responsible for this. However, the sequence of events leading to the discovery, his brief period of work at Agate in August 1904, and his premature return to New York, can be pieced together.

On July 28th, Peterson wrote Holland, stating "Since about the 18th of June we have had very good success to within the last few days. We leave this place tomorrow on a short trip to a new locality. I expect we will be gone some two weeks perhaps longer, if we meet with any success...." This letter has inscribed at the letterhead, "Agate P.O. Nebraska" indicating that he is leaving the next day for Agate and wishes Holland to have his postal address there. The date of July 28th is in agreement with a statement published by Peterson (1909, p. 70) in his entelodont monograph:

"One day in the latter part of July, I decided to break camp and go down the river in search of new localities for fossils and also to study the geological features of the neighborhood more fully. As Mr. Cook's ranch was on our way down the stream, it was decided to pay him a visit, and accordingly we stopped at his ranch. After a camp-ground had been pointed out to me, on top of a high butte immediately to the south of the farm buildings, and arrangements for wood, water, etc., had been made, the preliminary work of prospecting the neighborhood was at once under way. A day or two later Mr. Harold Cook, the eldest son of Mr. James H. Cook, accompanied the writer to a small elevation some four miles to the east of the farm buildings and immediately beyond the eastern limits of the land belonging to the ranch. The talus of this low hill was discovered to be filled with fragments of bones, and was afterwards designated as quarry A."

However, a later letter indicates that the start for Agate was briefly postponed, for Peterson became ill with fever after writing to Holland on July 28th, and went instead to Fort Robinson, about 30 miles east of Harrison, for medical treatment. The exact duration of his stay at Fort Robinson is unknown, but two to three days seems likely. If he departed Fort Robinson on August 1, he would have arrived at Agate late on that same day. His preliminary prospecting would have occurred on August 2nd. Thus Harold Cook possibly took him to Quarry A either on August 3rd or 4th. The first field label from Quarry A (or from any of the Agate quarries) in the archives of the Carnegie Museum is dated August 6th, and records the collection of rhinoceros. Horse, rhinoceros, and chalicothere remains are reported from Quarry A in field labels dated August 8th. On August 9th, a large carnivore metacarpal (Hunt, 1972, Fig. 13) was found at the future location of University Quarry at University Hill: there are no field labels dated later than August 9th.

Shortly after beginning work in Quarry A, Peterson (1909, p.71f.) discovered the main bone bed of the Agate hills: "We had worked three or four days in [Quarry A] when I decided to visit the two buttes (since named Carnegie Hill and University Hill by Prof. E. H. Barbour) which lie about three hundred yards to the south of the place where we were working. One may easily imagine the thrilling excitement of a fossil-hunter when he finds the talus of the hillsides positively covered with complete bones and fragments of fossil remains." Working with him at Agate were his assistants, T. F. Olcott and A. A. Dodd.

If the time table above is correct, then Peterson found the bones in the main hills some time from August 5 to 7, and thus Peterson could have worked at Agate only a very short time, for on August 10, he wrote to Holland announcing his readiness to end work for the season:

"As to the continuance of work in this locality I would say that we are not having the success we perhaps would have, were I able to work like I was accustomed to. This summer has been a trial on me from beginning till now. I have been troubled with dyspepsia from time to time. The next day after I wrote to you last [letter of July 28th] I was laid up with a fever instead of going as I expected to look up a new locality. I am just back from the hospital at Fort Robinson and I have been advised by the doctor to be careful in not exposing myself in this heat. I have about decided to quit collecting for a time and have taken steps accordingly.

So far as our institution the Carnegie Museum is concerned I can say that we have a magnificent collection from this locality which when worked up should be a pride to the Museum as well as to the collectors and preparators. I am glad to say that so far as I have been able to continue this summer, we have met with good success. In fact I have done some of my best work this season notwithstanding my condition....

As I do not think I am doing credit to myself or to the institution to continue here much longer I will close up in a few days and come in."

On August 16th, Peterson arrived in New York where he recuperated from his illness and arduous field season. Assuming three days by train (the usual rail time) to reach New York, Peterson must have left Agate about August 13th. If this is true, he could have spent only about 10 days in the Agate quarries in 1904. The only definite statement giving the date of Peterson's departure from Agate was made by Holland (Holland and Peterson, 1914) who wrote that Peterson "left for his home in Pittsburgh on the 10th of August." There is an evident discrepancy between this statement made by Holland, and Peterson's letter of August 10th in which he "will close up in a few days." It seems certain, however, that Peterson left Agate at some time between the 10th and 13th, and so could have only worked in the quarries for a week to 10 days at most.

Peterson's stay at Agate leaves many unanswered questions: (1) how much material was actually collected in 1904 from Agate sites, especially Quarry A? (2) what was the role of T.F. Olcott and A.A. Dodd who were his assistants? when did they leave Agate? (3) why did Peterson not mention the discovery to Holland in his letter of August 10th? (4) why did Peterson leave no field notes on the excavation of the principal site, Quarry A?

Although the trying events of the summer, particularly the developing discord between Peterson and Holland culminating in Peterson's ill health, could be responsible for the absence of detailed information on the discovery, the possibility exists that Peterson did complete notes on the Agate fieldwork which then did not find their way into the Carnegie archives. The eventual discovery of these notes would provide important information on the first field excavation at Agate.

1.2. James and Harold Cook

Although the first notice of bones in the Agate hills by a professional paleontologist belongs to Olaf Peterson, the Cooks and other settlers of the region had seen bones in these and other hills in the area for many years prior to the Carnegie discovery. James Cook emerges in much of the correspondence and narrative of the time as strongly concerned with bringing the bones to the attention of paleontologists. Peterson acknowledges a number of invitations from Cook to visit his ranch, prior to Peterson's journey to Agate. And among records in the American Museum, New York, there is an indication that James Cook had told J.B. Hatcher about the bones at Agate.

James Cook married Kate Graham of Cheyenne, Wyoming, in 1886. In 1887 they purchased the Agate Springs Ranch (then called the 04 Ranch) from Kate Graham's parents. According to Dorothy Meade, a granddaughter of James Cook, "A year or two before their marriage, when riding, Kate and Jim had discovered fossil bones weathering out on the ranch. Later, as owner, Cook reported this find to both the Nebraska and the Wyoming State Geologists."

Peterson (1909) supplied a published version of the discovery of bones at Agate as understood by him: "A few days later [in August 1904] when I reported my additional find to Mr. Cook, I learned that I was not perhaps the original discoverer of the bones in these two hills, as he told me he had seen bones there as long ago as 1890, but always thought them to be of recent origin. In 1908 I was further convinced that the bones in these hills had been seen even earlier by Mr. Octave Harris, a prominent ranchman of the neighborhood."

Harold Cook gives an amplified account of the discovery of bones at Agate in his book, Tales of the 04 Ranch:

> "Father had shown the two hills in the valley of the Niobrara, on which he had found fossil bones, to E. H. Barbour of the University of Nebraska in 1891; but Professor Barbour had no money at that time for collecting.
>
> "John B. Hatcher of Princeton University had been collecting dinosaurs in eastern Wyoming in the Lance Creek country. He came down into Sioux County with his brother-in-law, O. A. Peterson, who was collecting fossils for the Carnegie Museum of Pittsburgh, which had recently been built. One day when father ran across Hatcher and Peterson in Harrison, he told them about the fossil deposit near Agate, which he had shown to Professor Bailey, territorial geologist

for the state of Wyoming, and to Professor Barbour. Father suggested that they might find it interesting to come down to the Niobrara and see the deposit. At that time Hatcher and Peterson were taking out some skeletons in the Sioux County badlands [White River beds north of Pine Ridge]. It was near the end of their field season; they wanted to finish up; and so they did not come to Agate in that year of 1903.

"Toward the end of the summer in 1904, Peterson wrote that Dr. Hatcher had died during the winter [actually Hatcher died July 3rd, 1904].

" 'I recall,' he wrote, 'the invitation you gave us to come to your place to do some prospecting. Is that invitation still good?'

"Father answered his letter, saying that it certainly was. A short time later, Peterson and a boy drove into the ranch with a team and a light spring wagon. They stayed overnight. The next morning he told the boy to have the wagon and team harnessed and ready to go when he returned from the quarry hills, about three miles to the east.

"Peterson and I rode down on saddle horses. I had seen the fossil bones many times while working with the cattle, but I had not disturbed them. After preliminary inspection, Peterson was greatly excited. We rode back to the ranch immediately. He had intended to drive south into the North Platte country; but he waved his arms wildly when we approached the ranch.

" 'Put the team in the barn,' he shouted, 'we aren't going anywhere!'".

Study of the records and correspondence in the archives of the Carnegie and American museums indicates the general outline of this account accurately represents the events leading to Peterson's discovery, but some details are mistaken. First, Barbour of the University of Nebraska did not visit Agate in 1891, but first arrived there in 1892, and, as will be shortly discussed, he never visited the bone hills, relying instead on the judgment of one of his students who did reach the site. Barbour decided not to act on the student's information, and thereby lost the chance to excavate the quarries 12 years before Peterson's arrival.

Secondly, James Cook could not have told Hatcher and Peterson about the bone hills in Harrison in 1903, for Peterson never left the Carnegie Museum in 1903, working in the laboratory and not carrying out field work. In 1900, Hatcher worked in Sioux County, but not with Peterson, and in 1904, only Peterson was present. In 1901, Hatcher and Peterson were rarely together, and then for often only a brief visit in Harrison (on July 1st, and on July 30th); at this time Peterson was working the White River badlands north of the Pine Ridge in Sioux County. In 1902, during May and June, Peterson worked the Sioux County White River badlands but Hatcher remained in Pittsburgh where his daughter was seriously ill. Later in the season Hatcher traveled to Colorado from Pittsburgh, but whether he stopped in Sioux County is not known and seems unlikely. Moreover, this trip occurred near the end of the field season when Peterson had moved into the dinosaur beds of Wyoming, so it is doubtful that the two would have met. Thus, if Cook encountered the two field men in Harrison, it seems that the meeting most likely occurred in 1901. If this is true, the Carnegie men were aware of the possibility of a bone deposit at Agate for several years prior to Peterson's visit.

1.3. E.H. Barbour and the University of Nebraska

A discovery of the scientific importance found by Peterson at Agate perhaps comes once in a paleontologist's career, if at all. The least likely event in Peterson's mental scenario as he traveled east to Pittsburgh in August 1904 was that he would find himself in competition for the fossil resources of Agate in the summer of 1905. Yet this took place, brought about through the zeal of Harold Cook, unknown to Peterson. On May 26, 1905, Harold Cook wrote E. H. Barbour in Lincoln who, until now, knew nothing of the Agate bone bed:

> "Dear Sir:
>
> Reading that an appropriation had been made to carry on the work of Paleontology in this state, I thought you would be interested in learning of the recent fossil discoveries here. As you probably know, Prof. Peterson, of the Carnegie Museum, came out here to work a large quarry found last summer.
>
> Owing to some important work to be done at the museum, he had to return, leaving Mr. Olcott in charge of the work, but Prof. Peterson will return to the field later in the summer.
>
> I have since found an immense field, so large that they could not work it out in years, so that there is plenty of material for other parties to work with. So far there have been discovered here several varieties of rhinoceros, -at least one new species- the Mastodon, the Titanotherium, at least two varieties of the Camel, the giant Sloth Mylodon -never before discovered in the Miocene-, turtles, the three toed horse Anchitherium, several varieties of Oreodonts, several Carnivora, and other unclassified species.
>
> The bones for the most part are in excellent condition, especially after one gets under the surface. We are all interested in having the State Museum in the front rank, and Prof. Peterson says this is one of the best localities he has ever been in.
>
> If you come here, I believe we can put you on the track of all sorts of big game. It will take Prof. Peterson years to work the quarries they have now opened as there are simply innumerable bones in them. They have uncovered ten skulls in a place not more than six feet square, besides quantities of other bones. Papa saw Maj. Frank Wolcott in Denver at the Stock Convention, and told him about the bones here. He said he would speak to you about them when he got to Lincoln, but

it may have slipped his memory."

Barbour's reply was immediate and predictable. Ten skulls in 6 square feet coupled with Peterson's endorsement should have been enough encouragement for any professional. Barbour in this barely restrained letter pens a classic in a field where the ability to play the cards can often be as important as the luck of the draw:

"Mr. Harold G. Cook, Agate, Nebr.

"Dear Sir:

"Your letter came last evening about five o'clock, just after all of our offices had closed so I could not learn the exact conditions of the finances of this department. It is now Sunday and there will be no chance to make inquiry until Monday. However I shall not wait. Your letter is just what I wanted. Do you mean that you have a bone bed which is rather exclusively your own to which we could come and collect? Or is it the bone bed which some other college has opened and upon which there are the claims of others to be considered? You see it is often of doubtful propriety to work another man's quarry even though it is the public domain unclaimed.

"It seems to me that your letter plainly states that you have found a fossil bed of your own. If this is so keep it for us without fail and do not allow anyone to poach upon it. What you say is exactly true, everyone has been robbing the state of its very best things and the state itself has scarcely anything. Yale College has more specimens from Nebraska than we can collect in years to come. Likewise Chicago, Carnegie Museum, Columbia, Princeton, etc. This is all wrong, and I am very thankful that you view it in this way. Still what could we do? The museum has been overcrowded for the past eight years and they have asked me to suspend active work in the field. During the past year we have boxed and stored as much as fifty tons of our best exhibits. These were lowered and packed away in an abandoned steam tunnel running east and west under the campus. By no fault of mine we have been making progress backward in this matter for a number of years....

"In Wyoming the university buys its quarries, when they prove to be extra good, and in this way can continue work from year to year without the interference and poaching of other collectors. How much should we buy and at what price could it be bought? Would you advise us to buy? Is there any way in which we can get a claim upon it? Please advise me carefully. Are you at liberty this summer vacation? Would you be willing to conduct the work for us this summer? What compensation would be fair? Do you understand collecting bones? I have no fear whatever on this point.

"Is the quarry near your Ranch where you could work to advantage and comfort? While we are engaged in settling arrangements by mail, will you not go out to your 'find' and stake it out and put up some sort of a sign saying "Claimed by the University". This is done by all the colleges who collect in the badlands, and every collector respects all such prior claims.

"You will recall possibly that we discovered the bones in the region of Agate as early as 1891 and have quite a collection of such bones in the state museum together with the Twisters [the helical burrow fills] which occurred on the same horizon, so as far as rights of priority go, we have a prior claim on this region as a matter of fact. One reason why we should act with decision is this: collectors over the country ask me to direct them to these beds and in dealing fairly we are compelled to answer them. Only yesterday I was compelled to tell of the collecting grounds around Agate to a professional collector from the University of Kansas. He will skin the place. Please continue to stand by your own state in this matter.

"I shall make inquiry first thing in the morning and will see just what funds are available for field work, and if it is agreeable to you to undertake field work for us in your region. It seems to me that we can come to terms which will be fair and satisfactory all around. At the first moment I will visit you and look the ground over with you. In the meantime, act for me."

Barbour had been a frequent visitor to Sioux County since 1891. In fact, he might easily have been the discoverer of the quarries at Agate had it not been for his preoccupation with the 'devil's corkscrews', or 'Daimonelices', the names he gave to the fillings or natural casts of these Early Miocene rodent burrows. Barbour became fascinated by these gigantic fossils on a collecting trip to Sioux County in the summer of 1891.

On his first visit to Sioux County on June 29-30, 1891, Barbour was taken by a local resident of Harrison, C.E. Holmes, to the Eagle Crag locality of the Pine Ridge escarpment, a short distance north of the town. Here he saw for the first time the great helical burrows of the rodent _Paleocastor_ that so excited Peterson in July 1904 when the latter found rodent skeletons within the burrow spirals. Ironically, Barbour came to believe that these were the fossils of huge plants, largely due to the plant cells which were found in dense concentrations around the spiral cast and within its interior. He fielded his first major expedition to collect these 'corkscrews' in the summer of 1892, accompanied by several of his students.

Barbour arrived at the Eagle Crag locality on May 1, 1892, and collected approximately one ton of these burrows casts within a week. Later in June 1892 he and his associates returned to the area as the First Morrill Expedition of the University of Nebraska, exploring the "Daimonelix beds" (as he named the corkscrew-bearing rocks) along the Pine Ridge tableland. The Cooks, hearing of

Barbour's interest in the corkscrews, invited him to visit Agate to see the ones found at their ranch.

On July 7, 1892, Barbour and his party reached the Cook homestead at Agate in an intense rainstorm. After establishing camp, on the following day the Cook family guided Barbour to outcrops near the ranch containing superb rodent burrow casts. On July 9th, Barbour and his men excavated some of these corkscrews in the draws north of the Niobrara River. However, during the same day, one of Barbour's students, F. C. Kenyon, during exploration of the hills on the south side of the river, made the discovery that could have given Barbour first entrance into the Agate quarries. An entry by Barbour in his personal field notebook for Saturday, July 9, 1892, records the event:

> "Kenyon visited two hills 4 m. S [sic, above this S the letter E has been pencilled] of Cooks where the bones of Indian horses are reported to have been petrified. He finds Oreodon, Hyracodon [a rhinoceros], and other animals in considerable abundance, all are fragmentary however. Visit at another time."

In a darker ink written in and around this entry appear two State Museum field numbers given to fossils presumably found by Kenyon in the Agate hills. The first number (UNSM 15-9-7-92) bears the red stamp 'Discarded' above it, and in all probability no longer exists. A second number, UNSM 16-9-7-92, reads 'Claw-Megatherium-Mylodon. Probably belongs to higher beds.' This specimen I was able to locate: it bears the field number on the side, and also the phrase, '4 mi. S. of Cook Ranch, Agate'. It is the claw-like ungual phalanx of a large chalicothere (Moropus). Because the chalicothere phalanx bears both the field number, indicating that it was found on July 9, 1892, and the same erroneous designation as found in Barbour's 1892 field notes (4 miles south), there is not much doubt that it is one of the fossils collected by Kenyon and brought to Barbour to examine. Because it was mistaken for the claw of a sloth, it was assumed it must come from higher beds, since no sloths were known from the Early Miocene of North America. The type of preservation and color of this fossil leave no doubt it could have come from the main Agate sites.

Anxious to move north of the Pine Ridge into the White River badlands, the party left the Cook Ranch at 4 PM, reaching Harrison shortly after midnight. They rested in Harrison the next day, some attending church, leaving others to write letters, and going north into the badlands on Monday, July 11th. They had missed an incredible opportunity.

Barbour's preoccupation with the helical rodent burrows led to his failure to follow up Kenyon's discovery, and Kenyon was apparently too inexperienced to realize that these were not the bones of Oligocene oreodonts and the rhinoceros Hyracodon in the

Agate hills, but rather the rare remains of Early Miocene rhinoceros and chalicothere that would weather slowly on the slopes of the hills until Peterson's later visit of 1904.

As postscript, and additional confirmation, of the Barbour episode of 1892, Kenyon later wrote a narrative of the trip to Agate which he published in the American Naturalist in 1895. He mentions his own discovery, still unaware of the great bone deposit that he must have stood upon, but left unrecognized:

> "After three weeks of corkscrew digging in the vicinity of Harrison, we decided to make a short trip southward to the Niobrara, where, we were informed, screws of enormous size, some with tree-like tops, might be found. With the two teams that we had managed to hire in the town, we followed the trail over the prairie to the southeast. Once or twice we passed a lonely 'claim', but when these and Harrison had become hidden by the hills behind us, we could look for miles around without seeing a sign of human life.... Soon we found ourselves at the edge of the bluff bordering the Niobrara Valley on the north. The valley ... is not wide, not more than a mile. On the opposite side we could see the steep high bordering hills, and near them the small stream winding through the nearly level valley. By its side the log house of James Cook .... This was the Agate Springs ranch, whither we had been requested to come to see the giant corkscrews with tree-like tops....
>
> "The valley afforded very different scenery from what we had met with farther north. On the south, high steep hills rose up from the valley, on the north were high bluffs. Back through these northern bluffs numerous narrow canons had been cut in times long passed....
>
> "In the upper courses of these canons we found the 'corkscrews'. We certainly had not been deceived as to their size; the largest that we had seen in the neighborhood of Harrison were pigmies beside some that now presented themselves to view. Few of them were small. Stems and spirals nearly three feet in diameter were not uncommon, but they were not quite so regular and smooth as the smaller ones to which we had become accustomed during our three weeks digging. Many of them were found in which the great spiral seemed to end in a broad top [the burrow mouth opening out onto the land surface], but in no instance did we see any evidence of the tree-like tops that we had been told were to be found here....
>
> "As in the beds near Harrison, fragments [of the rodent burrows] were common. One, which came near being left in the field, was turned over and disclosed to view, imbedded in its mass, the legs and several vertebrae of an animal about the size of a large deer. The bones were clamped into the side of the stem just as a shell might be by a low-growing sponge....
>
> "The only other bones that were found on the north side

of the river was an Oreodon skull. This was dug out a few inches above the upper end of a 'screw'. On the hills of the other side of the river, however, fragments of Rhinoceros were not uncommon.... After a stay at Agate Springs of only a few days, [we] set about our return for Harrison."

And so Kenyon himself refers to the fragmentary rhinoceros bones on the south side of the Niobrara River, surely the bones of the main Agate hills. The existence of the chalicothere claw in the State Museum collection shows that he must have brought some of these fragmentary bones to Barbour, but the significance of these fossils Barbour failed to recognize.

2. GEOLOGIC SETTING OF THE AGATE FOSSIL BEDS

The bone bed at Agate is a fascinating and spectacular natural phenomenon -- a rare glimpse into a time long past, when the ancient land surface was home to a mammalian fauna much different from the present one. All the species of mammals found in the Agate bone bed are today extinct. Some of their descendants continued to live in this region for many millenia, but most lineages, and not just species, have died out entirely. So we cannot simply draw an analogy to a living animal to deduce the mode of life of the Agate species, for in most cases such close relatives no longer exist. No living representatives of groups such as chalicotheres, entelodonts, oreodonts, or beardogs have survived. Inferences must be made on the basis of skeletal anatomy of the fossils, and, by simultaneously drawing on knowledge of life mode of the closest living analogues to these extinct forms. Given these limitations, if additional relevant information about environment can be gained from study of the enclosing sediments, so much the better. Today's knowledge of the environments in which sedimentary rocks are deposited is much improved relative to what was known and practiced during the early Agate excavations; the local and regional geological setting of the bone bed can tell us much about its origin.

In addition to insights into the ancient environment, rocks also provide our estimate of time. Radiometric dating of key rock units is the primary means whereby an age is assigned to the bone bed. The bones themselves cannot be dated: the short half-life of carbon-14 prevents this, but distributed at various stratigraphic levels throughout the region are thin volcanic tuffs, made up largely of air-fall grains of volcanic glass and mineral crystals. Crystals with sufficient potassium can be dated by the potassium-argon method; both glass and minerals have been dated using the fission track technique. A regional geochronology has been built on dates derived from these volcanic tuffs, and used to calibrate the evolutionary faunal sequence based on fossil mammals (Evernden et al., 1964). Very few of the tuffs represent an undisturbed volcanic ash-fall. If carefully examined, the tuffs exhibit fine layering indicating deposition in shallow quiet water.

Most are reworked ash accumulations that have been transported to topographically low areas, such as shallow ponds, where water and wind have concentrated the loose ash after volcanic events.

2.1. The Cenozoic clastic wedge of the central Great Plains

During the mid-Cenozoic (about 5 million to 37 million years ago, the Oligocene and Miocene Epochs of geologic time), a great wedge of terrestrial sediments developed on the eastern flank of the Rocky Mountain front ranges (Fig. 2.1). Late Cenozoic uplift and erosion have removed much of the mid-Cenozoic sequence in the Great Plains, but in many places over one thousand feet of terrestrial sediments of the wedge remain. The Agate bone bed lies within sediments of this wedge.

The wedge is defined to include Cenozoic terrestrial sediments of the central Great Plains that occupy parts of western Nebraska, southeast Wyoming, northeast Colorado, and southwest South Dakota. Its northern boundary is the Pine Ridge escarpment (Fig. 2.1), which also marks the northern terminus of the High Plains. Its southern boundary is the southern escarpment of the Cheyenne tableland developed primarily in northeastern Colorado. The central part of the wedge is deeply dissected by the North Platte River, cutting completely through the wedge to expose pre-Cenozoic rocks at several locations; lesser incisions are made by the Niobrara River to the north, and Lodgepole Creek to the south.

Today two principal remnants of the wedge survive as topographically elevated tablelands of the central Great Plains, one to the east of the Laramie Range, the other east of the Hartville Uplift: (1) the Cheyenne Table, or 'Gangplank', is situated between the North and South Platte rivers at the juncture of Wyoming, Colorado, and Nebraska; Cenozoic sediments onlap the granite core of the Laramie Range; (2) the Hartville Table lies between the White-Cheyenne rivers on the north, and the North Platte River on the south, and onlaps the granites and Paleozoic carbonates of the Hartville Uplift.

Regional dissection of the wedge is relatively recent. Significant erosion began in the Plio-Pleistocene (0 to 5 million years ago), and it is possible that major dissection began only with the onset of continental glaciation and consequent lowering of regional base level. Aggradation of the wedge continued through the Late Miocene (until about 5 million years ago), based on preservation of Late Miocene fluvial rocks at high elevations on the wedge remnants. On the Cheyenne Table, the Ogallala Formation underlies a regional geomorphic surface sloping gradually eastward from the mountains that was not deeply dissected until post-Late Miocene time. To the north, Late Miocene (Hemphillian) fluvial sands and gravel assigned by Skinner and others (1977) to the Snake Creek Formation on the high topographic divide between the Niobrara and North Platte rivers indicate a similar history of late Cenozoic dissection for at least the southern Hartville Table.

The wedge has been divided into a number of geographically widespread rock units, or strata, which were primarily deposited by rivers, streams, lakes and ponds, and eolian (wind-driven) processes, including settling from the air of fine grains of silt and sand.

2.2. Stratigraphic sequence of the wedge

The major stratigraphic units of the wedge are found in both the northern and southern remnants (Darton, 1899), and have also been recognized beyond the immediate geographic area of the wedge elsewhere in the western Great Plains and in adjacent Rocky Mountain intermontane basins. Originally named on the basis of outcrops in and adjacent to the wedge, the widespread distribution of these units in the central Rocky Mountain region and the western plains reflects their importance as indicators of regional geologic history.

These rocks are primarily sands, silts, and gravels, with occasional beds of limestone and volcanic ash. Mineral and textural composition of rocks making up each of the major units tell much of their history, first described by N. H. Darton (1899, 1905), geologist with the U.S. Geological Survey. Darton recognized three stratigraphic units, the White River, Arikaree, and Ogallala formations, in ascending order.

As noted by Darton, and confirmed by many subsequent studies (e.g., Denson, 1969; Denson and Chisholm, 1971), the White River and Arikaree are rich in volcanic glass fragments which form a significant fraction of the rock. The Ogallala, on the other hand, although not devoid of ashy horizons, is predominantly sand, gravel, and silt derived from nearby Rocky Mountain uplifts, transported eastward down the surface of the wedge by streams and rivers.

Darton's distinction emphasizes an important change in lithology and style of sedimentation of the wedge sediments through time. The White River-Arikaree units include a major eolian component lacking in the Ogallala deposits. Much of the White River-Arikaree sequence comprises air-fall (pyroclastic) silt and fine sand -- although locally reworked by streams on the aggrading surface of the wedge, the bulk of the sediment comes from distant volcanic sources. Stream-produced bedforms are commonly overprinted on fine-grained pyroclastic sediments derived from air-fall events. In contrast, the Ogallala rocks are largely transported as traction and suspension load in streams crossing the wedge from west to east. The textural variety of Ogallala sediments is usually greater than White River-Arikaree deposits, as might be expected of stream sediments transported by currents of varying energy, when compared with eolian deposits. Lateral continuity of Ogallala subunits is

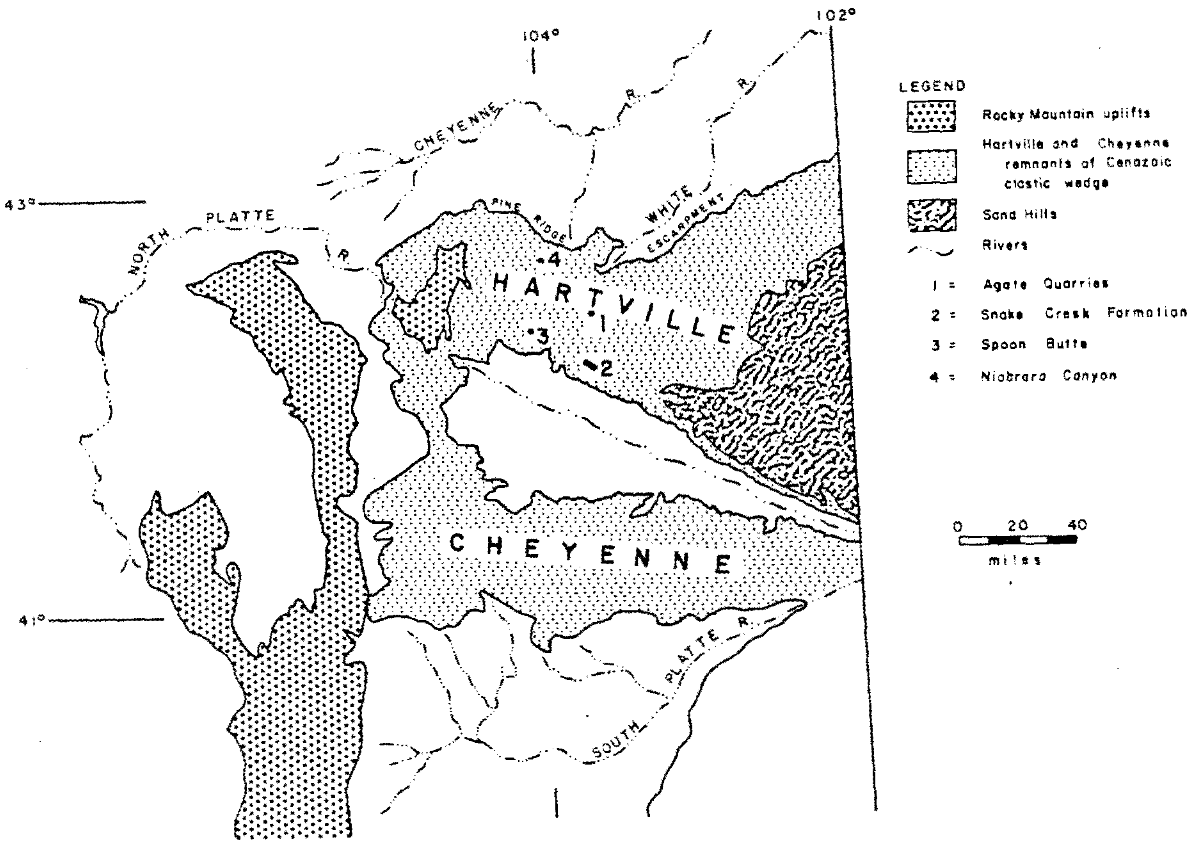


Fig. 2.1. During the mid- to late Cenozoic (37 million years ago to present), a thick wedge of continental sediments developed east of the Rocky Mountain uplifts. Today the principal remnants of the wedge persist as the Hartville and Cheyenne tablelands east of the Laramie Range. This clastic wedge was dissected during the late Cenozoic, as the modern rivers and their tributaries developed their present drainage pattern, but in the Late Miocene must have existed as a nearly smooth uninterrupted land surface sloping gradually eastward from the mountain front. The Agate quarries are located in Arikaree rocks of Early Miocene age that veneer the surface of the western Hartville table. These rocks, named the Upper Harrison beds by O.A. Peterson in 1907, were deposited largely as fine air-fall particles from volcanic activity in the Great Basin (Utah-Nevada) during the Early Miocene. The sediments gradually built a flat semiarid grassed plain, traversed by sandy ephemeral streams of low gradient that locally worked the fine volcanic sand and silt into stream channel fills. Shallow ephemeral ponds and lakes provided the only other source of water on these plains to herds of grazing mammals. The mountains to the west were nearly buried by the aggrading Cenozoic sediments, and so did not contribute significant amounts of sediment to the developing wedge. The stream courses were frequented by chalicothere and entelodont, and certain carnivores, possibly only during the wet season, when the open interchannel plains were probably home to oreodonts, small rhinoceros, camels, and horses. The Agate bone bed occurs in the base of the sediment fill of a major ephemeral stream valley that appears to cross the wedge between Spoon Butte and the Agate quarries.

nearly nonexistent, whereas such continuity within the air-fall White River and Arikaree often is observed.

Today we know that the tripartite sequence of units used by Darton is more complex than he initially realized. Naturally, the reconnaissance nature of Darton's geology focused on broad characterization. One expects such early efforts to yield to more detailed study with time. Clear-cut boundaries between Darton's units have not been identified: the distinction between White River and Arikaree rocks in the central Great Plains is difficult if one seeks everywhere a sharp lithic break between the two units. A belief that such a break must exist has resulted in a great deal of effort with little conclusive result, due to complex facies relationships and the gradational nature of sedimentation between the units in many places. Earlier, Lugn (1939) created a new major unit, the Hemingford Group, in the Nebraska panhandle for rocks intermediate in age (using land mammals) between Arikaree and Ogallala units -- however, the lithic distinction between Hemingford rocks on the one hand, and Arikaree or Ogallala rocks on the other, was never established. Despite such problems, the general character of the White River, Arikaree, and Ogallala as identified by Darton can be recognized in the field today. With careful definition and mapping, they can continue to serve the geologist as useful rock units in our attempt to understand the evolution of the Great Plains clastic wedge.

2.3. Regional geologic setting of the Agate Fossil Beds

The Agate bone bed on Carnegie and University hills occurs in an Arikaree-type sandstone: its mineralogy includes feldspar, quartz, and volcanic glass shards in about equal proportions. The bone bed is found in the base of a 30 foot sequence of stream-deposited fine sands, which overlie and incise a dark gray Arikaree sandstone below. Above these stream deposits is more Arikaree sandstone imprinted with soil features. Thus there is no doubt that the Agate bone bed lies within the Arikaree sequence in central Sioux County.

Arikaree sandstone forms the surface of much of the Hartville Table, to the west underlying the flat short-grass plains east of the Hartville Uplift, and to the east of Agate present but often covered by younger rocks. Although a pattern of southwest-to-northeast trending faults disrupts the Arikaree (Hunt, 1978, 1981), the measured offsets are usually of low magnitude (less than 100 feet vertical separation), so that the stratigraphic relationships of Arikaree subunits are clear. This makes possible the recognition of individual Arikaree formations over a wide geographic area. By using the geometry and internal structure of these rock units, we can reconstruct environments of deposition, and then build from these reconstructions the regional environmental setting that prevailed in the Early Miocene when the Agate mammals occupied the region.

Particular environments are commonly represented: (1) sands and silts worked by stream processes; (2) limestones formed in shallow ponds and lakes; (3) sands and silts driven and deposited by wind; (4) ancient soils, overprinted on the three above environments.

There is much evidence that the sand and silt grains that form the bulk of all Arikaree sediment come from two primary sources: (a) the Rocky Mountain uplifts to the west (epiclastic grains); (b) volcanic terrain to the west and southwest (pyroclastic grains). The epiclastic sediments are made up of grains eroded by water and wind from the mountains to the west, and are transported by streams eastward onto the surface of the gradually aggrading tableland. Coarse epiclastic debris does not extend far from the uplifts, comprising only a very small fraction of the total volume of Arikaree sediments. The pyroclastic sediments are composed of small grains carried by wind from volcanic centers located in the southern and central Rocky Mountains, and from more distant sources of silicic volcanics farther west in the Great Basin (Izett, 1968). Because volcanic glass shards make up such a large percentage of Arikaree sediment (about one-third), we see that the volcanic contribution to the rock is significant. The shards are ejected into the atmosphere by the explosive force of volcanic eruptions, and are carried by strong high altitude winds eastward over the plains. The grains settle out over the terrain as a relatively uniform blanket of volcanic debris, somewhat thicker and coarser-grained to the west near the volcanic source, thinner and finer-grained to the east. Many of the quartz and feldspar grains associated with the shards in Arikaree sediments are also volcanic in origin, because they have small pieces of volcanic glass fused to their sides. In addition, the potassium-feldspar minerals are sanidines, common in volcanic terrains, whereas microcline, a feldspar found in nearby uplifts, is rare. Probably more than 50% of typical Arikaree sediment is volcanic in origin.

Climate during Arikaree time is of particular interest in reconstruction of the Agate environment. A semiarid climate for the western High Plains segment of the clastic wedge is indicated in recent studies of Cenozoic sandstone diagenesis and groundwater chemistry (Stanley and Benson, 1979; Stanley and Faure, 1979). Particularly in the case of Arikaree rocks, the absence of pronounced diagenetic alteration of minerals and volcanic glass, the survival of unstable minerals, the predominance of friable sandstone with original pore space preserved, yet with little interstitial cement, and the fresh unworn outline of many grains attest to lack of significant climatic modification of these sediments since they were deposited. On the basis of this evidence, certain climates can be ruled out, such as persistently warm, humid subtropical to tropical regimes, where kaolinization of feldspars and destruction of volcanic glass would be expected. Alteration of Arikaree sediment is largely limited to soil processes overprinted on fluvial, eolian, and lacustrine environments of deposition. This lack of diagenetic interaction between sediment and interstitial groundwater probably resulted from the combined influence of (1) equilibrium conditions between minerals and groundwater (see Stanley and Benson, 1979); (2) a nearly neutral pH of pore waters; (3) a semiarid environment with only infrequent seasonal rainfall. These conditions limit pronounced sediment diagenesis to land surfaces where seasonal precipitation, plant cover of short grasses, and sediment characteristics combine to produce arid-land soils, in time evolving to duricrust. We also know that the climate through Arikaree time probably lacked prolonged cold winters, for crocodilian fossils occur in both the lower and upper Arikaree formations (a crocodilian tooth was reported from the Agate bone bed itself in 1919). This is reason to suggest mild winters similar to those occurring today in the southeastern United States. And the occurrence of wind-produced dune bedforms at many widespread Arikaree localities east of the uplifts indicates the availability of sufficient volumes of Arikaree sediment not stabilized by vegetation and, consequently, at least seasonal aridity. Thus a picture develops of a seasonally arid region with mild winters, probably subject to a climate typical of continental interiors, traversed by westerly winds, and removed from the moderating influence of oceans or other large bodies of water.

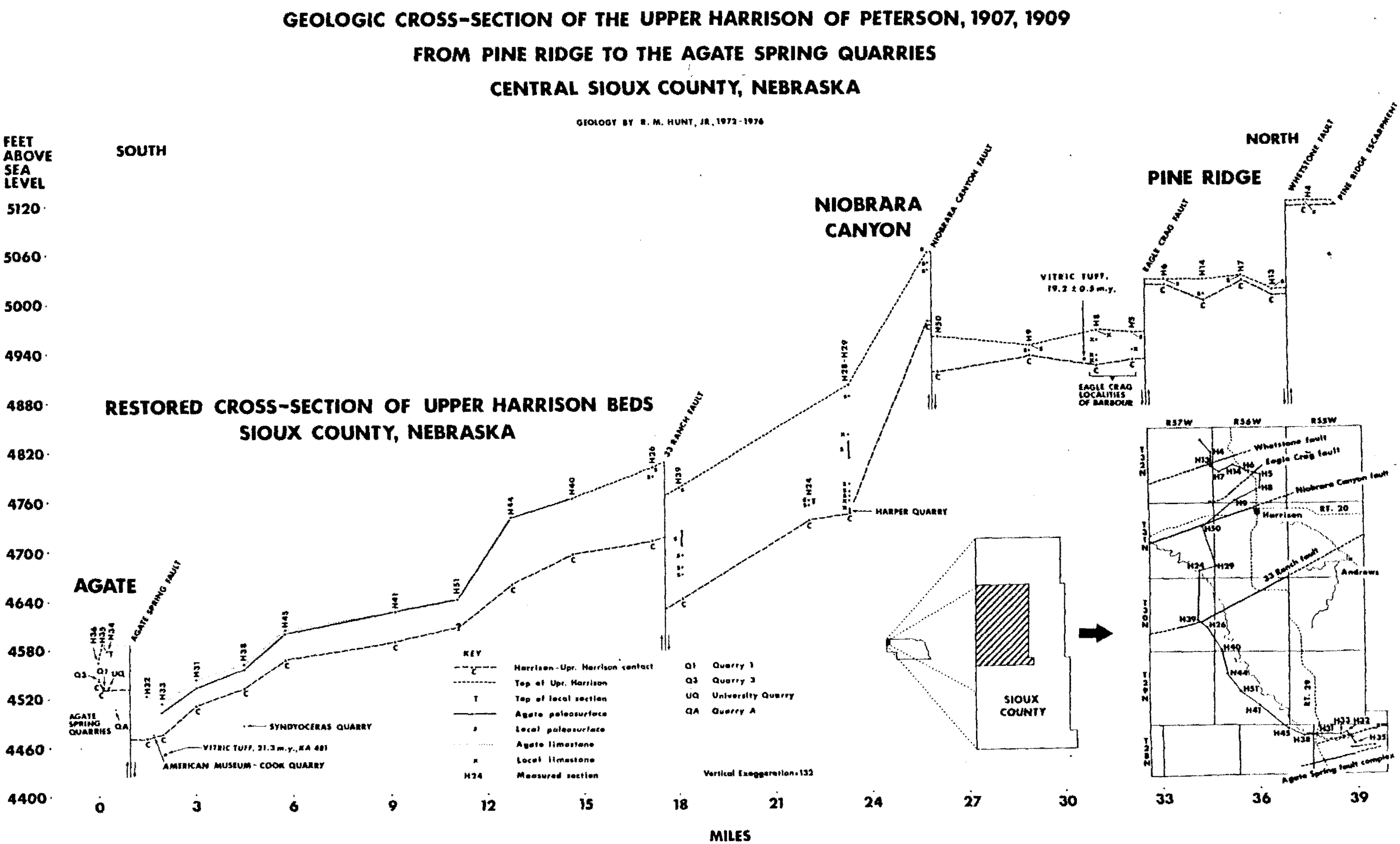
When we focus our attention on that part of the Arikaree that includes the Agate bone bed, we find a specific set of depositional environments represented over a wide geographic area of about 900 square miles east of the Hartville uplift in southeast Wyoming and northwest Nebraska. These environments are identified in rocks assigned to the Upper Harrison beds of O. A. Peterson (1907, 1909). The Upper Harrison beds are exposed at the surface of the tableland from its present western margin adjacent to the granite core of the Hartville Uplift south of Lusk, Wyoming, to the Agate area 40 miles to the east (Fig. 2.1). Upper Harrison outcrops have been identified as far north on the tableland as the crest of Pine Ridge northwest of Harrison, Nebraska, and as far south as the North Platte river valley, south of Guernsey, Wyoming. This area is similar in dimensions to the Serengeti plains of East Africa, west of the rift valley uplifts in Tanzania, and possibly was similar to them in physiography and climate patterns (see Schaller, 1972, pp.12-20; 1973, pp.3-43; Sinclair, 1979, pp.1-45).

Study of Upper Harrison rocks, in terms of their internal structures, geometry and composition, indicates three main depositional environments: (1) streams, primarily ephemeral; (2) shallow wide ephemeral ponds and lakes; (3) vast level interchannel plains. These environments have been identified by mapping the Upper Harrison sediments from the Niobrara Canyon in Sioux County (Peterson's type area) southeast to Agate along the valley of the Niobrara River (Fig. 2.2), a distance of about 20 miles (Hunt, 1978, 1981).

Sediments of the interchannel plains and the ephemeral streams are similar: fine sand and silt made up of fresh, relatively unworn grains of feldspar, quartz, and glass. These plains undoubtedly were blanketed by air-fall pyroclastic debris that settled out of the atmosphere following distant major volcanic eruptions. The uniformity of grain size of Upper Harrison sediment over a wide area is evidence of this. Local ephemeral streams, running in wide shallow channels similar to modern ephemeral drainages of the Great Plains, reworked this air-fall sediment into fluvial bedforms. There is very little evidence at this time of sediment influx from the nearby Rocky Mountains (Laramie Range, Hartville Uplift, Black Hills); a fine granitic gravel found to date in only one Upper Harrison paleovalley remains the only evidence of debris from the cores of nearby uplifts. Erosive power of streams is not manifested in the form of major down-cutting by these drainages. The deepest valleys measured in the field are 100 to 150 feet in depth. Perhaps more significant as a measure of the availability of surface water in the region is the general absence of Upper Harrison channel-fill deposits over much of the tableland.

Interspersed through the vertical extent of interchannel Upper Harrison deposits are ancient soil horizons, indicating the presence of level extensive geomorphic surfaces that can only be interpreted as widespread interchannel plains. These paleosols are flat, with a gentle paleoslope to the southeast, normal to the structural axis of the uplifts to the northwest; they are densely packed with relict plant roots which appear to belong to grasses, based on the very small diameter of the root vestiges (a hollow core surrounded by a silica rind of weakly crystallized montmorillonite probably produced by dissolved glass shards). Some of the paleosols can be traced for many miles (Hunt, 1981, Fig. 2, p.270), indicating broad flat interchannel expanses east of the mountains, much as the arid short-grass plains occur marginal to the African rift uplifts in Tanzania today.

The soil horizons are siliceous duricrusts (the 'siliceous grits' of J. B. Hatcher, 1902). Once fully formed, an impermeable crust would have prevented access to the water table by the surface flora. Plants would have had to rely on meteoric precipitation, and arid-land grasses would be likely colonizers of such an environment. That the surface of the duricrust was not far beneath the land surface during the time it formed is proven by the presence of many subaerially weathered fossil mammals, primarily oreodonts (Merychyus), preserved in partial articulation within the upper part of these duricrusts. Their bones are cemented by opaline silica into the crust in the same manner as the parent sand grains. Petrographic thin sections of the duricrust, when viewed under the microscope, frequently show empty cavities having the shape of volcanic shards, thus shard dissolution probably contributed to the cementation of the crust. Once the crust formed an impermeable horizon, the overlying soil was probably quite thin, at best a few inches, and could have sustained only plants capable of survival in



GEOLOGIC CROSS-SECTION OF THE UPPER HARRISON OF PETERSON, 1907, 1909
FROM PINE RIDGE TO THE AGATE SPRING QUARRIES
CENTRAL SIOUX COUNTY, NEBRASKA
GEOLOGY BY R. M. HUNT, JR., 1972-1976
FEET ABOVE SEA LEVEL
SOUTH
NORTH
AGATE
AGATE SPRING FAULT
AGATE SPRING QUARRIES
SYNDYOCERAS QUARRY
VITRIC TUFF, 21.3 m.y., KA 481
AMERICAN MUSEUM - COOK QUARRY
RESTORED CROSS-SECTION OF UPPER HARRISON BEDS
SIOUX COUNTY, NEBRASKA
33 RANCH FAULT
HARPER QUARRY
NIOBRARA CANYON
NIOBRARA CANYON FAULT
VITRIC TUFF, 19.2 ± 0.5 m.y.
EAGLE CRAG LOCALITIES OF BARBOUR
PINE RIDGE
EAGLE CRAG FAULT
WHETSTONE FAULT
PINE RIDGE ESCARPMENT
KEY
Harrison - Upr. Harrison contact
Top of Upr. Harrison
Top of local section
Agate paleosurface
Local paleosurface
Agate limestone
Local limestone
H24 Measured section
Q1 Quarry 1
Q3 Quarry 3
UQ University Quarry
QA Quarry A
Vertical Exaggeration = 132
SIOUX COUNTY
R57W
R56W
R55W
Whetstone fault
Eagle Crag fault
Niobrara Canyon fault
Harrison
RT. 20
33 Ranch fault
Andrews
RT. 29
Agate Spring fault complex
MILES

FIGURE 2.2

thin immature soils without access to ground water, and able to utilize seasonal rainfall, such as arid-land grasses.

Further confirmation of the existence of level open semiarid terrain is the presence of thin widespread limestone beds (micrites), containing gastropods and smooth-shelled ostracods, interpreted as the calcium carbonate muds of shallow ephemeral fresh-water ponds and lakes. Such pond limestones are common in the Niobrara Canyon, Eagle Crag, and Agate areas in Sioux County, where they sometimes rest on siliceous duricrust, showing that their existence in such cases is due to the impermeability of the hardpan. No organisms requiring permanent water are found in these fine-grained limestones -- only invertebrates and algae that can survive rigorous environmental conditions, particularly desiccation (Hunt, 1978). Often the limestone will have been overprinted by a soil following the drying of the pond; burrows, root vestiges, and mudcracks are common in such beds.

Thus, the evidence derived from the Upper Harrison sediments suggests a semiarid climate, without a prolonged cold winter, and probably with a dry season interspersed with periods of intense rainfall. Rainfall of the wet season(s) is responsible for sediment transport, deposition, and reworking of the bedload of ephemeral streams, and for the replenishment of ephemeral ponds. With each return of a dry season, the dried stream beds and pond deposits are subject to working by wind, subaerial weathering and bioturbation; and with return of sufficient moisture, the development of vegetation yielding soils. Again, a parallel to the Serengeti ecosystem is plausible. Just as the Crater Highlands of Tanzania shadow the Serengeti plains, the semiarid Hartville plains are a probable response to the rain shadow of the Rocky Mountain uplifts during the mid-Tertiary period. Ephemerality of streams and ponds, broad level interchannel areas armored by duricrust, colonized by plants with nearly uniform small root diameters, suggesting grasses, and, as we have recently discovered, the predominance of particular mammals in stream deposits (chalicothere, entelodont, large beardog), and of other species in interchannel areas (oreodonts, camelids), all come together to suggest such an environmental scenario.

2.4. Local geologic setting of the Agate Fossil Beds

The Agate bone bed occurs in one of the ephemeral stream deposits of the Upper Harrison beds. To understand how the bone bed formed, and why it is so exceptional in the region, we must take a closer look at the sediments in the two main Agate hills, and at the nature of the bone bed itself.

The sediments in the two main hills are nearly identical in vertical stratigraphic sequence. This proves that no major physical barrier separated the two present day bone beds on University and Carnegie hills, and indicates that the sediments were laid down in one ephemeral stream system. The cliff section in the Southwest Excavation at Carnegie Hill is the best exposed rock sequence, and its windward orientation accentuates bedding as well as numerous sedimentary structures. It can be subdivided into four sedimentary subunits from the base of the hill upward: (1) dark gray Arikaree sandstone of the Harrison Formation, restricted to the base of the two main hills, and forming all of North Ridge where it contains Carnegie Quarry A and the Agate Ash; (2) stream-deposited light gray to buff-white Arikaree sandstone of the Upper Harrison beds, about 30 feet thick, lieing on an irregular eroded Harrison surface, and containing the bone bed at its base; (3) about 20 feet of apparently massive light gray to light orange interchannel sandstone of the Upper Harrison with evidence of soil development; (4) a 1-2 foot thick fine-grained limestone (micrite), brilliant white in tone, capping Carnegie Hill, and locally termed the Agate Limestone (Hunt, 1978).

Here, stacked one on top of the other, we see Upper Harrison depositional environments that at one time in the Miocene must have existed side-by-side in lateral relationship: ephemeral stream, overlain by interchannel deposits, capped by an ephemeral lake. The bone bed, then, was part and parcel of the Upper Harrison environments most commonly encountered in the region, and is not found in a rare or atypical depositional setting. We cannot blame the mass grave on an atypical depositional environment.

Since the depositional setting does not seem to be unusual, we can turn to the mammals. Are such concentrations of mammal bones commonly found in ephemeral stream deposits in the region? The answer is no; such accumulations on the scale and magnitude of Agate are exceptional. Harper Quarry, located in the Upper Harrison beds about 20 miles northwest of Agate (Niobrara Canyon, Fig. 2.1), contains a concentration of mammal bones in what has been judged to be a cut-off stream channel segment, or peripheral floodplain pool (see Hunt, 1978). Bones are disarticulated, their surfaces often abraded by stream activity, and broken by predators and scavengers. They seem to have been aligned by stream currents. Isolated teeth and bone fragments are common, making up about 40% of the initial sample from the quarry; these are the logical end-products of skeletal destruction by environmental agencies, demonstrating that many bones were not quickly buried but remained exposed on the land surface for a time. Teeth from the quarry, whether still in jaws or isolated in the sediment, are most often from old or very young individuals, and include few adults in their prime. All evidence at Harper Quarry points to an attritional bone accumulation preserved within or near an ephemeral stream environment.

A second example of the Upper Harrison mammal fauna within an ephemeral stream channel system is found at Spoon Butte (Fig. 2.1) astride the Nebraska-Wyoming state boundary. These rocks and their mammalian fossils have recently been studied by Robert Skolnick and James Vanderhill, graduate students at the University of Nebraska. At Spoon Butte, the Upper Harrison beds fill a large paleovalley about one-half mile wide which has been dissected by late Cenozoic erosion to reveal the valley's profile and its contained sediments in much detail. A wide variety of microenvironments are represented: ephemeral streams, ponds, volcanic ash beds, floodplain deposits, diatomaceous earths, and channel floor lag gravels. In this broad spectrum of sedimentary environments, greater than that found at Agate or Harper Quarry, we have not yet found a concentrated mass of bones of few species of the Agate type. Bones on the contrary are generally disarticulated, scattered, broken and gnawed by scavengers, with surfaces often cracked and checked through weathering on the land surface. Just as at Harper Quarry, considerable wear on teeth, or the lack of it, shows that most mammals are very young or old; prime adults are not common. Again, this is an attritional bone assemblage, the flotsam of daily life in a wide shallow ephemeral valley meandering eastward across the plain from the nearby western hills of the Hartville Uplift.

The Spoon Butte and Harper Quarry bone samples exemplify the typical bone residue of Upper Harrrison ephemeral streams. The great number of bones packed in at Agate, and their lack of diversity (Agate mammals are nearly all rhinoceros, chalicothere, and entelodont) contrast sharply with the more spatially dispersed and taxonomically diverse bone samples found in Upper Harrison ephemeral streams elsewhere in the region. Agate is distinctive not only in the great number of bones found there, but also in its lack of mammalian species diversity.

We can increase our insight into the problem by looking more closely at the Agate bone bed itself.

2.5. <u>Origin of the Agate bone bed</u>

The origin of the bone bed in the main hills at Agate has never been carefully investigated. The most obvious features of the bone bed are by now well known, and this information, largely acquired during the early excavations, led to a number of hypotheses (Table 1) on the origin of the bone deposit. Most were initially proposed prior to the end of intensive excavation at Carnegie Hill in 1923, and so were based on the firsthand field observations of the paleontologists who had exposed the bone bed. Thus these hypotheses must be taken seriously, for these men saw aspects of the bone layer that no recent investigator can fully appreciate.

On the other hand, these early investigators were not inclined by training to observe and collect certain kinds of data on sediments and fossils that today are known to be extremely useful in reconstructing the origin of such a deposit. Nevertheless, some information of this type can be gleaned from their field notes and maps, and combined with our recent work, so that a preliminary reconstruction can be made. It is this first attempt that appears here in this report. A more thorough study based on field data is in progress which, when completed, should allow the various hypotheses on the origin of the bone bed to be properly evaluated.

Table 1. **Hypotheses on the origin of the Agate bone bed, 1906 - 1980**

a.	Peterson	1906	Lacustrine Origin
b.	Peterson	1909	Drowning at River Ford
c.	Holland	1914	Attritional Deaths at Floodplain Pool
d.	Matthew	1923	Floodplain Pool with Quicksand
e.	AFBA*	1964	Great Flood or Quicksand
f.	Schultz	1966	Great Flood or Quicksand
g.	Macdonald	1980	Drought

*Agate Fossil Beds Association

There is no concensus in the scientific or popular literature on the origin of the Agate bone bed. Early scenarios that attempted to explain the bone bed failed to distinguish observation from interpretation, and did not discriminate among questions of **time, process, and sequence.** To decide the bone bed's origin, it is useful to know: (1) the amount of time involved in formation of the bone bed; (2) the process(es) responsible for the bone bed and its enclosing sediments; (3) the sequence of events prior to, during, and following the formation of the bone deposit.

The resolution of time, process, and sequence is at the heart of all paleoecological analysis (Fig. 2.3). They are truly separate issues, since a process can act continuously or episodically in time, and at different rates. In addition, two or more processes can produce a different end result by occurring in a different sequence over time.

The tools available to the paleontologist to solve these problems are the study of pattern in sediments and fossils, and the measurement of geologic time using radiometric methods. Immediately, we can say that events of very brief duration in human terms, on the order of minutes, hours, and days, cannot be resolved using modern methods of radiometric dating. Such small time increments are beyond the current resolving power of geochronology. If analysis of sediments at sites such as Agate indicates that the deposit could have been formed by events of very short duration, we will not be able to resolve such a small amount of time with present methods. We can only point out that such a possibility exists.

The study of pattern in the analysis of sediments and fossils is an exercise in analogy. We reason from pattern to process by making the assumption that patterns observed in the rock record are the result of processes that have been occurring throughout the latter part of Earth history. Modern sediment patterns are studied to determine the modern processes that created these patterns. When we find the same patterns in the ancient rock record, we infer a similar process, and thereby arrive at an understanding of how the ancient situation developed. This method can even result in some

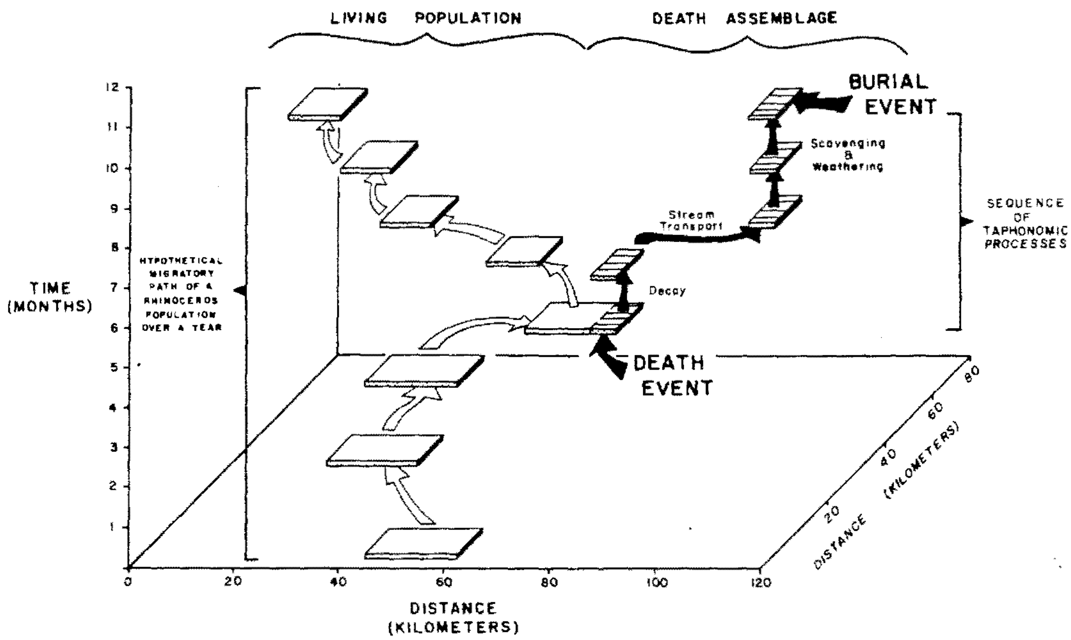


Fig. 2.3. The history of a mammalian death assemblage is patterned by three variables: time, post-mortem processes, and the sequence in which such processes act on the death assemblage. Here one of many possible scenarios is diagrammed to show the relationship of these variables to the resulting bone accumulation preserved through a burial event. A migratory rhinoceros herd loses a portion of its members to a death event (e.g., lack of food, disease, sudden death by drowning). The carcasses are subjected to the taphonomic processes of decay, transport, scavenging and weathering. Over time, the mass of carcasses is reduced to some degree by these processes, soft tissues are lost in greater proportion relative to hard tissues, and the death assemblage is actually spatially displaced. If the processes occur in another sequence, if they operate over a different amount of time, or if other processes are involved, the nature of the bone accumulation derived from the death assemblage will differ. Evidence acquired through observation of fossil and sediment patterns is used to reconstruct the history of death assemblages. Such reconstructive efforts attempt to separate the effects of time, process, and sequence in a bone deposit.

greatly different from Harper Quarry. Moreover, University Quarry apparently is not the only such deposit in the main hills: the North Excavation on Carnegie Hill appears to have many of the same characteristics, although the records and fossils that survive today are not as satisfactory as those for University Quarry.

On the other hand, the densely bone-packed 'Diceratherium bed' and American Museum chalicothere site located in the Southwest Excavation at Carnegie Hill tell a different story. Many bones are relatively fresh and unabraded; all ages are represented in the deposit, including prime adults. Diversity is low as it is in all quarries on the two main hills (rhinoceros and chalicothere make up 99% of all material), but here the low diversity is emphasized due to the greater number of bones/sq.ft. relative to the other quarries. W.D. Matthew (1923) calculated bone densities averaging about 100 elements/sq.ft. for the bone-packed American Museum exhibit slab removed from the Southwest Excavation in 1919, and estimated an average bone density for the Southwest Excavation in its entirety of 40 bones/sq.ft. Evidence of predator-scavenger activity, while known, is poorly documented. The evidence for associated and articulated skeletons here is the highest of all the quarries (in the two main hills) -- often field correspondence suggests that associations of bones would be found in the laboratory when the field blocks were prepared. Matthew (1923) wrote: "[The bones] are seldom articulated, but most of the bones of a single skeleton lie near together, although some parts may be found at a little distance." Most important, however, are the firm statements by Matthew and H. F. Osborn of the American Museum that many of the individuals of the chalicothere sample from the north end of the quarry represent associated individuals. This _Moropus_ sample, limited to a small area of the Southwest Excavation, could represent a local population swiftly killed by catastrophe, and not an attritional bone accumulation.

There is, then, a demonstrable lack of homogeneity to the pattern of bones in the quarries of the two main hills. It is possible that the bone bed does not represent a single death event, but results from multiple events. Following the death event(s), various processes act in a particular sequence over some unknown amount of time. The number and sequence of pre-burial processes place their identifying stamp upon the bones, but this stamp is not always so clear that discrimination of one process from another is easily achieved. Figure 2.3 diagrammatically portrays the relationship between time, process, and sequence in the case of a single death event that befalls a mammal population during an annual migration. The diagram conveys the potentially complex history of such a death assemblage, via the processes that influence it prior to burial. In reconstructing the history of death assemblages in the fossil record, it is necessary to observe sediments and fossils, and, despite their incompleteness, infer process, sequence, and time. From this evidence, a limited number of scenarios like Figure 2.3 can be constructed. From these scenarios, one can be chosen as most probable. Or several can be indicated as best expressing the present degree of uncertainty on the origin of the bone deposit. At Agate, some of the quarries contain a mixture of attritional skeletal debris of apparent long exposure to the Miocene environment, and other sites show less processed dense jack-strawed bone piles recording what may be a catastrophic event(s) that wiped out populations of chalicothere and rhinoceros. A detailed study of the bone bed is now in progress to obtain the information needed to adequately construct scenarios in agreement with the known evidence from fossils and sediments. Let us turn to the sediment pattern and try to gain insight from a different quarter.

2.5.2. Sediment pattern in the Agate bone bed

The depositional environments represented on the monument by Upper Harrison rocks are ephemeral stream channel and floodplain, widespread ephemeral lakes, and flat interchannel plains. Because the Agate quarries on Carnegie and University hills are restricted to the channel sediments, we know that the bones reached their final resting place in a stream environment. The channel sediments in the two main hills at the level of the bone bed and for a few feet above it show horizontal stratification, accompanied by convoluted bedding and low angle cross stratification, which are common in some modern ephemeral streams.

Although margins of these local channels are found in the two main hills (and are mentioned in the early field correspondence), ephemeral stream deposits have a much wider distribution in the monument area. They fill a wide shallow paleovalley whose southern margin has been identified about 1.75 mile to the south (Vicars and Breyer, 1981). The nature of this valley margin also suggests that it belonged to an ephemeral stream: a vertical shallow stream bank of partially lithified dark gray Harrison sandstone stands adjacent to piles of small to large angular blocks that have fallen from the bank into the stream as the bank was undercut. The angular blocks, jumbled together as unsorted debris, indicate local bank collapse. Such poorly lithified blocks could not survive in a perennial stream, but only in seasonally arid ephemeral drainages. In fact, such bank collapse blocks can be seen today in draws within the monument boundaries only a short distance away.

It is well known that ephemeral streams undergo sediment transport primarily at times of intense seasonal rainfall, with stream flow occurring as flash floods often of considerable volume. These flood deposits are characterized by a variety of bedforms. In modern flood sediments of Bijou Creek, Colorado, McKee and his co-workers (1967) found a high percentage of horizontally stratified sediments, some units with convoluted bedding, and a more limited volume of cross-bedded deposits, these last occurring at times of waning flow or at the periphery of the deposit. Vicars and Breyer (1981) identified horizontally laminated sands with convoluted bedding in the 5 foot-thick sandstone that includes the Agate bone bed, and indicated an ephemeral stream origin for this rock unit at Carnegie Hill and elsewhere on the monument. On the other hand, Williams (1971), in a study of flood deposits produced by modern sand-bed ephemeral streams of central Australia, found that over 60% of these deposits exhibited trough cross-stratification produced by migrating large and small scale ripples. Again, Vicars and Breyer (1981) observed that most channel sediments of the Upper Harrison paleovalley at Agate show shallow wide trough cross-stratification, produced in a sandy braided stream. However, modern ephemeral stream sediments are not well studied. There remains much to be learned about the range of bedforms found in modern ephemeral streams, and what dictates the internal structure of the sediments. Although an ephemeral sandy braided stream valley now seems to us a good contender among various hypotheses, we remain open to new evidence as detailed study of the quarry sediments continues.

If ephemeral stream processes could be reponsible for the sediment pattern in the quarries, let us next ask how much time is involved. First, there are no radiometrically-datable ash beds in the sediments of the main hills other than the Agate Ash (see Section 3.1.1), so the accumulation time of these rocks cannot be directly measured by radiometric dating. About 5 feet above the base of the bone bed, a local fossil soil (paleosol) is developed on both University and Carnegie hills. This same paleosol is found to the south at Beardog Hill where the large carnivore burrows found there are intrusive through it. It shows that a period of time long enough to produce a moderately-developed soil horizon interrupted the depositional process within the ephemeral stream channel, which at Carnegie Hill includes 30 feet of stream deposits. Thus, although the upper 25 feet of stream deposits at Carnegie and University hills are very likely ephemeral stream sediments, these higher beds have nothing to do with the development of the bone bed itself, since they are separated from it by the paleosol. Now if we examine the upper 25 feet closely, we find evidence of bioturbation (primarily plant roots and small invertebrate burrows) at many levels (e.g., Vicars and Breyer, 1981, Fig. 11). Each bioturbated level indicates a halt in sediment accumulation and the passage of sufficient time for vegetation to develop on this surface. These bioturbated stream deposits and the soil horizon five feet above the bone bed confirm that considerable time could be involved in the deposition of the entire 30 feet of channel sediments in the two main hills.

The 5 foot thick bed containing the bone layer at its base requires more detailed study than we have given it at present. Until this is completed, we can only summarize some of the features of the bed that pattern it: (1) its mineralogy and texture are no different than the channel sediments above it -- a fine to very fine-grained sandstone made up of about equal parts of volcanic glass, feldspar, and quartz; Vicars and Breyer (1981) demonstrated that Upper Harrison stream sediments in the Agate area are low in silt and clay (11%-17%), whereas interchannel deposits have as much as 39%; (2) although primary bedding has been obscured over much of the bed by bioturbation, there is evidence throughout of horizontal stratification and convoluted bedding -- if this is true, this would seem to rule out W. D. Matthew's view (1923) that the bone bed is a quicksand deposit, for in a quicksand, the regularly bedded horizontal layers would be largely destroyed (additional evidence that argues against the quicksand hypothesis is the existence of a 'double bone layer' on the north side of Carnegie Hill (see Sections 3.3.6, 3.3.8); (3) convoluted bedding is most common in the 5 foot thick bed relative to the overlying stream deposits at Carnegie Hill and University Hill -- Collinson and Thompson (1982) state that "Convolution involves plastic deformation of partially liquefied sediment soon after deposition.... The main use of convolute lamination is as evidence of rapid deposition."; (4) the bone bed itself is in some places 1 to 2 feet thick, and steeply inclined bones often vertically span at least one foot (or more) of the bed in highly unstable orientations; -- these orientations show that many bones must have been supported by sediment at the time they came to rest in the bone bed, and so at least 1-2 feet of the 5 foot thick bed was deposited rapidly at one time.

Turning to the floor of the bone bed, there is abundant field data and even photographic evidence that the surface was very irregular in places. This was reported by Pepperberg in University Quarry (and can be seen today by the casual visitor), by Barner and Thomson in the North Excavation, and by Thomson in the 1920 extension of the Southwest Excavation. Photographs as well as Pepperberg's data show that these irregularities are often steep sided grooves incised into the sandstone which can be filled with bones. As far as we can tell, they range from a few inches to up to about 1.5 foot deep, and several feet in width. We know that the Harrison sandstone forming the floor of the bone bed was about as well lithified at the time the bone bed came into existence as today, for we often find lithified pieces of the sandstone in basal lag conglomerates in the immediate area. Thus it took stream energy to cut these grooves; they were probably not incised by a single flood event.

If we draw on observations of the bone bed made by Peterson, it seems that the channel floor irregularities were probably present long before the formation of the bone bed was completed. Peterson and others noticed that the base of the bone bed often contained bone fragments worn to the shape of a pebble, and that such material was generally restricted to that level in the deposit. Harper Quarry also contained such worn bone pebbles. They represent a bone gravel that forms as a channel floor lag of long duration, and indicates a period in which the channels were probably starved of sediment. Only bone was of sufficient density and particle size, after breakdown and weathering, to form gravel-sized clasts that remained as bedload.

Having looked at small scale irregularities of the bone bed floor, let us consider the channel floor geometry on a somewhat larger scale. In July 1983, we surveyed the base of the bone bed in the various quarries, and graphed the resulting data to determine its degree of topographic relief. A profile, roughly normal to the channel axis, places the Southwest Excavation with its less damaged and seemingly associated bones on one side of a low topographic rise of a few feet; and on the other side of this rise, we find the more damaged and worn bone accumulations of the North Excavation and University Quarry.

About 8 feet of topographic relief occur along the transect beginning at University Quarry on the northeast, and extending to the southwest into the Southwest Excavation on Carnegie Hill. The bone bed at University Quarry marks the lowest point of the profile. The bone layer seems to rise toward Carnegie Hill where it is about 5 to 6 feet higher in the North Excavation on the north side of Carnegie Hill. This is a rise of 1.7 feet/100 ft. between the adjacent bone beds on the two hills. Continuing to the southwest, the highest point of the profile is reached at Carnegie Quarry 2 (Northwest Excavation of Carnegie Hill) where the bone bed floor is 8 feet higher than the floor at University Quarry. This is a rise of about 1.8 feet/100 ft., nearly identical to our first calculation. However, over the last leg of the profile between the Northwest and Southwest Excavations on Carnegie Hill, the bone bed descends about 4 feet in 120 feet. It is possible then that the Southwest Excavation with its associated chalicothere skeletons and numerous rhinoceroses is separated by a low topographic rise from the apparent attritional assemblages of the north side of Carnegie Hill and University Hill. Such evidence must be looked at carefully, since the rocks in the Agate hills have been structurally deformed following Early Miocene time. However, the tilt or dip of the Agate hills is to the northwest by only a few degrees at most; our transect was taken from northeast to southwest along strike of the Miocene beds, and so should not be affected by the local structural deformation to any significant degree.

Finally, both Charles Barner and Bill Thomson of the American Museum reported a double bone layer in the North Excavation on Carnegie Hill. This is so frequently mentioned by Thomson in 1917-19 that he must have been confident of its existence. Although two levels of bones within the five foot thick sedimentation unit below the local paleosol does not have to indicate that the two layers are separated by appreciable time, it is a possibility that must be considered. This was the only quarry where such a 'double layer' was described.

Although there is much more to learn about the sediments in the Agate hills, for the moment we can summarize the evidence at hand, and formulate a preliminary interpretation. Analysis of the geometry of the Agate paleovalley, its infill of sedimentation units, and their primary sedimentary structures and bedforms suggests that the bone bed lies within a sandy braided ephemeral stream environment. Stream flow was probably episodic, and concentrated at times of seasonal rainfall. However, the amount of time necessary to deposit the 30 feet of stream-laid sediments in the two main hills is uncertain, but the presence of many rooted and burrowed horizons in these sediments indicates that appreciable time could be involved. Significantly, the 5 foot thick sedimentation unit containing the bone bed is bounded by an erosional disconformity below and a paleosol above. Shallow, narrow, steep-sided channels or grooves cut into well-lithified bedrock, and a lag deposit of rounded bone pebbles and debris, characterize the disconformity, indicating that significant time is represented at this horizon; considerable time must also be involved in the development of the paleosol. Nonetheless, the intervening 5 feet of sediment between the paleosol and the disconformity could have been rapidly deposited, on the basis of primary sedimentary structures seen within the bed, such as convoluted bedding and horizontal stratification, a conclusion also supported by numerous unstable bone orientations within this bed in certain parts of the bone deposit. Five feet of sediment can be deposited in a single present-day flood event in ephemeral streams in semiarid regions (McKee and others, 1967), although we do not know that to be true at Agate. To best understand the bone bed, subsequent studies will focus on this 5 foot thick sedimentation unit above the disconformity and below the local paleosol.

2.5.3. <u>Agate scenario: 1984</u>

Scenarios are interpretive reconstructions. Let us use the evidence and observations in the preceding discussion of sediment and fossil patterns to create a probable scenario for the Agate bone deposit. We can combine analysis of our three variables (time, process, sequence) to produce a range of possible scenarios, and then, against this background, briefly evaluate the principal early hypotheses on the origin of the Agate bone bed.

Time remains an enigma; we cannot be certain how long the bone bed took to form. However, we can recognize time as either represented in the quarries by a continuous record of sediments or by an interrupted or episodic record. When the lowest five feet of the channel sediments in the quarries are examined, there is no evidence of a prolonged break in deposition until the paleosol level is reached five feet above the base of the bone bed. The lack of homogeneity of the bone pattern in the various quarries, yet the occurrence of the bones in a bed of sediment with very similar features on both hills, indicate that multiple sedimentary processes are not required to produce the 5 foot stratum that includes the bone layer at its base. The sediment burying the bone bed could have been continuously deposited at one time, and the evident similarity in this five foot bed among the various quarries in its primary features suggests that it was the result of a single event.

The presence of convoluted bedding, and the unstable inclinations of many bones, indicates that the sediment was probably rapidly deposited. We are actually inferring something about time from sediment pattern; the homogeneity of the bone bed in terms of its internal structure and thickness beneath the paleosol show that a single process could be responsible. The simplest interpretation is that a process acting through a single event produced the observed sediment pattern.

If the sediment pattern is homogeneous, causing us to invoke no more than a single sedimentation event, then sequence is no longer an issue since we are dealing with only one depositional episode. But the heterogeneity of the bone bed itself tells us that multiple processes acting over time may have been responsible for the distinctive fossil patterns that we observe in the different quarries. In essence, the burial of the bone bed may represent a single event, but the history of the death assemblage prior to burial could be varied, resulting in processed versus unprocessed portions of the bed.

The subsequent discussion (Section 3) of the various Agate quarries on Carnegie and University hills reveals that the northern (University Quarry, North Excavation) and southern (South Excavation) sites are characterized by scattered and fragmented bone concentrations. Densely-packed, more complete bones are found in the Southwest Excavation, which is located between the northern and southern quarries. If the bones were transported to this place by a single event, such as a flood, and immediately buried by stream sediments, these patterns of density and completeness of individual elements would have to have been established and maintained by stream processes prior to burial. Fragmented and abraded bones would have been segregated from fresh, generally intact bones. Since density and size of many broken fragments would be the same as intact bones, this seems unlikely, and we are forced to reconsider the view that the bones were deposited in the bone bed through a single depositional event.

However, we can consider an alternative view: let us still assume that the sediments were deposited at one time as a single burial event, but let the variables be (1) the amount of time and (2) degree of bone processing that have occurred <u>prior</u> to the burial event. In the first case, let us imagine that bone aggregations in the various quarries have arrived at these sites at different times, and not in a single event, such as a flood. Those assemblages which have been present at the site for the greatest amount of time will be most susceptible to environmental processing (e.g., scavenging, weathering, trampling). Recently arrived bone aggregates, on the other hand, will be least likely to undergo such progressive destruction by processing, and could remain largely intact except for disarticulation of bones. In the second case, the degree of bone processing might differ throughout a large mass of carcasses due to selective nonrandom scavenging concentrated primarily at the more easily accessible margins of a bone aggregation relative to the center. Clearly, this spatial variability in bone processing will be superimposed on the variability due to time alone, and the identification of that part of total bone attrition caused by one or the other of these variables will be very difficult to discern. Therefore, when the resultant fossil bone bed is exposed to view by the paleontologist, the bone deposit will reflect the aggregate sum of time spent at the site as well as selective processing, prior to the synchronous burial event.

It becomes apparent that we may not be able to work out the exact sequence of events that produced a given bone assemblage, other than to say that certain processes must have been involved. In the case of the Agate bone bed, the evidence is in accord with a single burial event, but we cannot discriminate between processed and unprocessed areas of the bone bed in terms of the relative contribution of selective processing versus the amount of time the bone assemblage was vulnerable to processing. At Agate, the acceptable hypothesis must take into consideration the similarity of the sediments enclosing the bone bed, but at the same time allow the diverse fossil patterns found in the quarries. At present, several such hypotheses are in agreement with the known evidence.

In attempting to arrive at an hypothesis on the origin of the bone bed, the evidence itself primarily acts to restrict our reasoning on a number of points: (1) the sediments enclosing the bones probably were deposited after some or all of the bone bed was present at the site; (2) the processed nature of the bone assemblage in University Quarry, and probably also those from the North and South Excavations on Carnegie Hill, could have been the product of climatic weathering, scavenging, and stream transport over a long period of time -- it will be difficult to reach an accurate estimate of the time involved in these more fragmented parts of the bone bed; (3) the dense intact bones of the Southwest Excavation are less processed than other parts of the bone bed, and according to early students of the deposit, still maintain significant parts of individual skeletons in near life association -- the attritional process(es) that operated on other parts of the bone bed are not as evident.

A number of scenarios can fit this evidence: (1) the bone bed was developed at the site over a brief time interval, perhaps a single season, but the margins of the bone mass were vulnerable to predators, scavengers, and other destructive agencies whereas inaccessible parts of the bone mass remained largely intact; (2) the older parts of the bone bed are represented by the more processed bone assemblages, whereas the less damaged bone deposits are more recently arrived at the site -- the degree of fragmentation and scattering of bones is directly proportional to the time spent at the site; (3) some combination of (1) and (2) has occurred to produce a highly complex bone bed.

To choose between these is presently premature. Additional evidence is needed to determine the relative contribution of time versus selective processing in creating the bone bed as we see it today. Field investigation will add concrete observations that can help resolve these issues. What we can see at the present time is that the sediments enclosing the bone bed are homogeneous but the bone bed itself is not. The most useful observations will include a close study of the various parts of the bone bed in different quarries, a rigorous examination of the 5 foot thick mass of sediment that occupies the base of the stream channel and extends upward to the paleosol (and includes the bone bed at its base), and investigation of the possibility that parts of the bone bed are separated in time. Of particular interest will be the spatial relationship of attritional bone concentrations such as the North Excavation to the better preserved bone bed of the Southwest Excavation on Carnegie Hill.

We can set the stage for the search for new evidence by evaluating the earlier hypotheses on the origin of the bone bed. What do they have in common? How do they differ? Is the evidence clearly set down, and is interpretation carefully distinguished from observation?

A. Peterson's Lacustrine Hypothesis

In 1906, shortly after his discovery of the bone bed, Peterson argued that the sediments enclosing the bones formed in a lake, based on his identification of "laminated structure" everywhere in the bed, which he identified "sometimes at one or two miles distant from the quarry." At the time, Peterson was not aware that he had confused the bone bed with the Agate Ash (see Section 3.1.1). The ash is laminated in outcrop, and is widespread over the monument (see Map K), but the bone bed is found only in the Agate hills. Because of this error in correlation, the lake hypothesis is no longer valid.

B. Peterson's River Ford Hypothesis

In 1909, after the conclusion of the major excavations by the Carnegie Museum in the main Agate hills, Peterson argued that the bone bed was deposited in a stream. His best evidence was threefold: the bones were "often closely packed in irregular channels and pockets", "the surfaces of the bones are sometimes highly polished and worn, and there are numerous fragments of bones which are worn down to the shape of a pebble." He elaborated further, "In the quarry located on University Hill there are distinct evidences of narrow and rather shallow channels, which were separated by sandbars of greater or lesser dimensions. The bone layer of this quarry is thus, irregularly separated, although confined to one general level throughout portions of the base of the hill." This is the sum of the evidence presented. Peterson followed these observations with his scenario: "It seems reasonable to suppose that in the immediate vicinity of the Agate Spring Fossil Quarries the ancient fauna of the region found a favorite crossing of this stream. The remains of the unfortunate animals which attempted to ford the river under unfavorable circumstances furnish the records which the collector is fortunate in securing ...."

Implicit in Peterson's scenario is death by drowning. But whether this involved mass drowning in a flash flood or seasonally swollen river, or simple attritional mortality by selective drowning of the old and weak at the ford, is not explicitly stated. At the time he wrote this, the large chalicothere sample of the Southwest Excavation had not yet been discovered. His viewpoint is based on the excavation of the predominantly rhinoceros-packed bone bed of Carnegie Quarry 1, where the bones are largely intact, disarticulated, and generally of one species. He evidently visualizes the carcasses carried from the ford to their resting place in the stream bed by currents, followed by their disarticulation, and sediment burial, but does not describe in detail how this took place. The issues are left unresolved.

C. Holland's Attritional Floodplain Pool Hypothesis

As in most scenarios of the time, Holland presents a few points of evidence, then from them launches a rather elaborate scenario on the origin of the deposit. His observations include: (1) bones are primarily disarticulated; (2) rare articulated vertebrae with attached ribs, and articulated limbs occur; (3) many bones in the quarry are unabraded, but some are worn, particularly those in the lower part of the bone bed. Holland also noted that unabraded bones of a single individual chalicothere (CM 1604) were found above a level of abraded bones in Quarry 1.

Holland's scenario (Holland and Peterson, 1914) is the most specific in its attribution of the bone bed to gradual attritional accumulation of animals through predation and scavenging, and in its description of the regional setting:

> "The region, at the time when the bones were deposited, was probably a great plain, traversed by a broad and shallow river, like the Platte, or the Missouri, subject at times to overflows. It was a region of flat alluvial lands, which may in the summers have been in part dried, leaving here and there pools of water to which the animals of the region resorted, as in South Africa at the present time herds of ungulates resort to such places. Any one who is familiar with the writings of C. J. Anderson and Gordon Cumming can picture to himself the conditions. At these pools the beasts, which roamed over the wide plain, came to drink, and here they died, as the result of age, or as they fell under the teeth and claws of carnivora .... After a period of summer drought or after the cold of winter, which must likewise then, as it does now, have led to the death of multitudes of creatures, the rivers rose as the

result of rains, or melting snows, and the waters swept the dried carcasses of the dead and sometimes those of animals, which, unable to escape from the floods, were drowned, into places where they were destined to lie ...."

If Holland's hypothesis is correct, the bone bed should reflect the attritional processes that created it. Individual bones would show the marks of predation and scavenging, and the death assemblage would include many of the old, the very young, and the weak. However, Holland invokes two processes in the production of his bone bed: (1) attritional mortality at waterholes; (2) catastrophic death by drowning in floods. Despite his emphasis on death at the pools, his mention of drowning in flood waters allows him to explain intact carcasses such as the chalicothere (CM 1604). He reinforces this multiple causality by quietly acknowledging Peterson's river ford hypothesis -- "It may also have been, as suggested by Mr. Peterson, that at this particular point there was a ford, or crossing of the river, much resorted to by migrating herds of animals, and here many, especially younger animals, were mired in quicksands, and drowned."

His viewpoint probably was much influenced by Peterson's field evidence and discussions, and Peterson's earlier published remarks on the origin of the bone bed. This can be documented in reference to the mention of quicksand, for correspondence indicates that Peterson first noted the idea in 1908, yet did not make published mention of it. However, it is fair to say that the core of Holland's hypothesis involved death by attrition at pools as a primary contributor of carcasses to the bone bed, with secondary input from stream ford deaths, and so differs from Peterson's 1909 concept. But surprisingly, when discussing stream ford deaths, Holland argues for the deaths of young mammals in quicksands, and not by drowning in swift water.

Holland's scenario includes for the first time to my knowledge the concept of herd migration as the implicit reason behind the fording of streams, and the mass drownings that might accompany such events. Because of the occurrence of the bones within an ephemeral stream system, catastrophic death by drowning is an event that could contribute to the Agate bone bed. Such events are well documented for wildebeest in the Serengeti ecosystem of East Africa during their annual migrations in search of adequate forage (Schaller, 1972, 1973; Maddock, 1979; Sinclair, 1979, Chap. 4), and are not as unusual as one at first might think. Even the attritional bone residues in some quarries in the two main hills could derive from this same process, but are simply farther along the path to total skeletal destruction than the largely intact bones of the Southwest Excavation. One could argue that such a scenario is more probable than Holland's, because his dual origin (waterhole, river ford) should yield a greater diversity of species in the attritional bone assemblages derived from the waterholes than in the catastrophic bone assemblage derived by drowning at a ford. Instead, we find the same three mammal species in all quarries. Yet, confirmed attritional bone deposits in Upper Harrison ephemeral streams elsewhere in the region do exhibit greater species diversity than the Agate bone bed.

D. Matthew's Floodplain Pool with Quicksand Hypothesis

In 1923, after the conclusion of work by the American Museum in the Agate quarries, Matthew penned a semipopular account of the Agate excavations. Because of H. F. Osborn's failure to publish his Agate chalicothere study, Matthew's narrative emerges as the principal account of the Agate work by an American Museum paleontologist. His observations deal with the Southwest Excavation: (1) the bones are densely packed in a layer 6" to 20" thick; (2) articulated bones are seldom found, but "most of the bones of a single skeleton lie near together, although some parts may be found at a little distance;" (3) most bones belong to only three species of mammals; (4) the small rhinoceros is most abundant and "has been found everywhere in the bone layer;" (5) a sample of 17 individuals of the chalicothere Moropus was localized at the north end of the quarry; (6) bones of other mammals that occur in the quarries are rare, and when found, are always waterworn; (7) based on an estimate of 40 bones/sq.ft., 4100 sq.ft. in the Southwest Excavation yielded 164,000 rhinoceros bones which, at about 200 bones/individual, indicates 820 Menoceras.

Matthew's scenario begins with a regional overview, as did Holland, then becomes quite specific in his explanation of the bone bed. Quicksand is central to Matthew's hypothesis:

> "The formation [containing the bone bed] is a rather soft sandstone of light gray color, made by the accumulated floodplain sediments of a river that flowed eastward across the plains, for then as now the region was one of open country and grassy savannas. It is believed that the accumulation of bones was formed in an eddy in the old river channel at a time when the valley was not so deeply cut out as it is now and when the river flowed at the higher level. A pool would be formed at this eddy, with quicksands at its bottom, and many of the animals that came to drink at the pool in dry seasons would be trapped and buried by the quicksand. The covering of sand would serve to protect the bones from decay and prevent them from being rolled or waterworn by the current, or from being crushed and broken up by the trampling of animals that came there to drink. But sand of this kind is always moving and shifting (whence its name of quick) and with it the buried bones would be shifted around, disarticulated, and displaced, so that when finally buried deeper by later sediments of the river valley, they would be preserved as they are found here, complete and almost undamaged, yet all separate and dissociated."

Matthew's quicksand theory (1923) seems implausible primarily due to the absence of any mammals other than chalicothere, entelodont, and rhinoceros in the quarries. Matthew was aware that this was a problem with the quicksand theory, and he candidly admitted it as a 'curious limitation.' A further objection is the presence of relict bedding (Vicars and Breyer, 1981, Fig. 2) in the 5 foot thick bone bed below the paleosol in the two main hills, and the existence of a 'double bone layer' in the North Excavation (see Sections 3.3.6 - 3.3.8) on Carnegie Hill. We can be certain that the attritional debris in University Quarry is not a quicksand deposit, and this probably applies to the North Excavation on Carnegie Hill with its two bone layers separated by about three vertical feet. But the situation is not as clear at the Southwest Excavation, and this is the quarry Matthew used to formulate his hypothesis. Could it be a quicksand marginal to attritional stream channel accumulations?

Certain aspects of the bone bed in the Southwest Excavation are suggestive of a highly fluidized sand (quicksand): (1) convoluted bedding and grain size (very fine sand); (2) polished bone surfaces; (3) disarticulation of bones yet proximity of parts of individual skeletons; (4) proximity of many individuals of the chalicothere sample at the north end of the quarry; (5) absence of any pronounced indication of scavenging or breakage of bones. It is easy to see why Matthew might arrive at quicksand as the critical factor in formation of the deposit. Looking carefully at the evidence, however, one realizes that the bones, not sediments, are the primary influence in his thinking; in fact, as noted earlier, the relict bedding in the bone bed argues against a quicksand. Perhaps we should ask which of the preceding observations on fossil bones could only have been produced by or are only in accord with a quicksand deposit, or, if these observations can be accounted for by some other present-day process?

Let us first reduce Matthew's observations to a few essential summary points: (1) bones of individuals are somehow kept together until final burial; (2) bones acquire a surface polish during their time in unconsolidated sediment; (3) it must be possible to keep together a part of a population of over 15 chalicotheres of all sizes; (4) post-mortem weathering and scavenging must have been minimal.

The disarticulated condition of the bones, yet their near association in individual skeletons in the bone bed (Matthew, 1923), could be explained from observations of modern mass deaths of wildebeest in East Africa. Schaller tells us that when ungulates of the size of the small Agate rhinoceros die in the dry season in the northern extension of the Serengeti, he could walk up to skeletons encased in their sun-baked leather-tough hides and, kicking these carcasses, make the bones inside rattle. Flooding following the dry season will pick up these bone groups within each hide, and maintain the association of each individual's skeleton, as it carries them downstream to a burial site within the stream channel. In a recent film (Year of the Wildebeest) made by Alan Root on the Serengeti wildebeest, the cameras actually recorded this very event, and the sequence ended with footage of a pile of hide-bound wildebeest carcasses which would be swiftly entombed en masse should a mass of sediment suddenly inundate them at this time in the stream channel.

So it is possible to bring together and transport long-dead carcasses by stream processes and still maintain skeletal associations. This is best accomplished in semiarid to arid environments where drying out of the carcasses will occur. Such carcasses also may remain largely free of scavenging. Schaller (1973, pp. 214-215) writes:

> "Many wildebeest died around Kogatende in the 1967 dry season. We found 46 carcasses there with the skeletons still articulated and encased by dry skin, indicating that no large predators had fed on them."
>
> "Every year many wildebeest drown when herds cross rivers. Lions scavenge only a few of these. For example, 62 wildebeest drowned in one pool near Seronera in June, 1967, seven more died there in June, 1968, and 83 in April 1969, yet none were eaten by lions."

Thus it is possible that the bones of the Southwest Excavation represent masses of carcasses of small rhinoceros and chalicothere that died of drowning and/or malnutrition and disease, as do ungulates today in East Africa. Stream processes then produced the final aggregation, but may be the actual cause of death of only some individuals.

Serengeti wildebeest provide many useful insights into the origin of the Agate bone bed. They are small antelope of about the same body size as the small rhino Menoceras. Wildebeest congregate in herds; large numbers of rhinoceros found in quarries near Bridgeport, Nebraska, Guernsey, Wyoming, and Agate suggest herding behavior in Menoceras as well. Wildebeest feed on grasses, and so must follow the growth of grasses as their seasonal abundance varies in different parts of the ecosystem. During the wet season, when grass is growing, they occupy the open plains west of the rift valley uplifts. As the dry season commences, they migrate westward down the Serengeti wedge (the clastic sediments underlying the Serengeti plains also have a significant volcaniclastic component, derived from rift volcanoes, and so are similar to ash-rich sediments of the Great Plains 'wedge') into wooded grassland, and then slowly north toward the Kenyan border where food is available. With the first rains, they return to the south, and during this journey of over 750,000 migrating animals, they cross flooded streams and rivers as a matter of course. Schaller and other authors document the death by drowning of hundreds of wildebeest at these crossings; such events would kill adults in their prime as well as calves and older animals. Interestingly, Schaller observed that the proportion of males is high in these drownings, because males act as leaders and are disproportionately common at the front of the herd. After examining all the major collections of Menoceras skulls and jaws from the Southwest Excavation in various museums in the United States, I was struck by the large numbers of males present. An accurate count is difficult to make, due to the frequent absence of the sex-specific incisors in lower jaws, and the loss of the rostrum in skulls (which supports the horn bosses found only in males), but it remains an intriguing possibility that many males occur at Agate due to preferential sampling of a male-dominated vanguard.

E. Peterson's Commentary of 1923

In 1923, Peterson published a brief paper on the Carnegie Museum exhibition slab of rhinoceros bones taken from the Southwest Excavation on Carnegie Hill in 1908. Although he did not speculate at length on the origin of the bone bed, his remarks indicate his continued support for a stream setting for the deposit. However, this publication marks Peterson's most detailed recounting of the evidence observed by him at the bone bed, and, coming after most work at the quarries had ceased, it is the most complete statement in existence by one of the principal field men involved at the site:

1. the bones form in places a solid pavement
2. skeletons are usually more or less disarticulated
3. some partially articulated skeletons were observed -- one of these was found between layers of disarticulated bones
4. abraded bones are concentrated near the base of the bed
5. most material is unabraded
6. the thinner parts of the bone bed have primarily fragmented and more scattered bones, in a well sorted sand matrix -- the bones are probably well mineralized and are blue in color
7. the thicker parts of the bone bed have dense intact masses of bones, some partially articulated, in a matrix of sand and carbonate -- the bones are not as well mineralized and are lighter in tone

Peterson concluded his remarks without elaborating on the origin of the deposit: "The shallow portions of the bone layer of these quarries have the appearance of the sediments of swifter flowing channels, while the heavier beds would represent deeper or more sluggish movement of the stream." It is unfortunate that Peterson and Albert Thomson, the two men who were probably most familiar with the quarries through prolonged excavation, did not write in more depth on their view of the origin of the bone bed. Much of the firsthand observation of value in the quarries we owe to these two men.

F. Commentary by Agate Fossil Beds Association

In 1964, a short publication was produced by the Association to promote the designation of the bone bed at Agate as a national monument. In an unattributed section of the pamphlet on the geologic history of the region, an anonymous author presents his scenario:

> "Weathering and erosion of the uplifted Rockies during the late Oligocene and early Miocene resulted in a rapid increase of sedimentary deposits upon the Great Plains. Because of increased gradient, the streams flowed swifter than before, and carried more and coarser sediments. Great floods took place, at which time many animals no doubt were trapped in rapidly rising waters and their carcasses swept downstream to be deposited at a bend of a river or other places where the waters were slackened. Then river sediments covered the remains. This process was repeated, in some cases several times at the same place, until layer upon layer of animal remains were sealed beneath the earth's surface.... Others believe differently, one theory being that the animals became trapped in quicksand when coming to the river to drink and sank into an ancient quagmire. In any event, the conditions that brought about the large concentrations of animal remains within a relatively short period of time must have been unusual indeed."

Much in this statement is now known to be inaccurate: (1) the bulk of late Oligocene and early Miocene sediments are not derived from the adjacent uplifts but from distant volcanic terrains; (2) there is no evidence of increased stream gradients, and the local stream sediments do not include markedly coarser sediments -- the Agate bone bed itself is made up primarily of very fine grained sand; (3) the conditions that produced the bone concentration at Agate may have not been unusual at all; for example, flood events may have regularly drowned herd ungulates as documented today on the Serengeti plains -- in fact, the joint occurrence at the site of both a major sedimentation event and the bone accumulation at a particular point in time is more likely the unusual event, and thus responsible for the existence of the bone bed.

G. Schultz's Great Flood Hypothesis

In 1966, in a popular article on the Agate National Monument, C. B. Schultz speculated on the origin of the bone bed:

> "The sands, silts, and clays were washed into the area from the eroding ancestral Rocky Mountains to the west. Many of the sediments represent floodplain deposits, some of which must have been quite distant from the streams. It probably was a prairie land and perhaps treeless, except for the wooded

> areas along the streams and in the lower areas of the shallow valleys. There must have been great herds of animals to be seen in all directions. The rhinoceros ... was undoubtedly the most common since the remains of this animal were encountered most frequently during excavation in the quarries.... [Next follows mention of Matthew's well-known estimate of 16,000 rhinos in the quarries on Carnegie Hill.] It is difficult to imagine how so many animals died in one place. Perhaps there was a great flood and tens of thousands of animals were drowned. Their carcasses were then carried downstream and deposited at bends of rivers and also scattered along the floodplains. The remains must have been quickly covered because of the completeness of so many of the preserved fossils. There is also some evidence suggesting that the animals perished in quicksand rather than a flood."

This scenario is extremely similar to the preceding account in the Agate Fossil Beds Association pamphlet, and both were possibly written by Schultz. Again, a critique of this scenario would emphasize the need to distinguish primary evidence from interpretation. It would stress the derivation of sediments not from the Rocky Mountains but from distant volcanic sources, emphasize the fact that true floodplain sediments are not common and are restricted to the rare ephemeral stream valleys of the region, and dispute the belief that because a species is most abundant in a fossil deposit, it was also most abundant in its life environment. In truth, these small rhinoceroses are quite rare in other ephemeral stream sediments in the region, and the great number of individuals found at Agate is atypical. Finally, the belief that tens of thousands of animals drowned is improbable, based on the proportion of modern ungulates which have died by drowning relative to the total population count in modern environments such as the Serengeti ecosystem.

Deaths by drowning in the most abundant Serengeti antelope, the wildebeest, whose modern population attains one-half to one million individuals in the Serengeti ecosystem, reaches only several hundred individuals at one death event (Schaller, 1972, p.215,235; 1973, p.31,36; Sinclair, 1979, p.96). The maximum number reported in these accounts is more than 3000 animals that drowned during lake crossings in 1973 (Sinclair, 1979), but in this instance these were entirely calves. To drown 20,000 or more ungulates of all ages in one flood would be nearly impossible in any modern environmental setting.

Despite these numbers, the total effect on the population of such mortality events is negligible, as Sinclair (1979) states: "Despite the high losses on some of these occasions, drowning forms a small proportion of the total annual mortality and, hence, has an insignificant effect on the population." Sinclair's work suggests a strong relationship between the amount of food available per individual and mortality in the dry season. Such death through malnutrition and starvation seems a more reasonable source of large accumulations of ungulate carcasses in plains environments of the Serengeti type.

H. <u>Macdonald's Drought Hypothesis</u>

In 1980, Macdonald proposed that a prolonged drought created the mass of carcasses at Agate. His points of evidence are as follows: (1) "The vast numbers of rhino skeletons preserved at Carnegie Hill and University Hill provide paleontological evidence that the drought must have lasted for several years;" (2) the rhinceroses died in the drought "by the hundreds, and thousands. Mixed with the carcasses ... were other victims, occasional chalicotheres, giant pigs, oreodons, cats and dogs, and a variety of equally thirsty smaller animals;" (3) the bones occur as "a gigantic mass of jackstraws, ... piled in a tangled mat 30 centimeters (12 inches) thick, covering an unknown number of hectares ... they were moved far enough to get thoroughly jumbled, but not far enough to be badly broken or much eroded by the action of water."

Macdonald's scenario is speculative, and emphasizes these points: (1) fluctuations in food supply result in fluctuating population numbers, thus at times of limited resources, animals will die in large numbers from lack of food; (2) the fossil evidence indicates a prolonged drought occurred at Agate; (3) the river in the vicinity of Agate ceased to flow, leaving only a few pools standing in the floodplain, which were used by the small rhinoceros and other mammals; the standing pools and others dug by the expiring animals proved inadequate to sustain these populations and many died; (4) later rains filled the dry river bed, and swept the rhino carcasses "and lesser numbers of the bones of other animals" downstream for "a few hundred meters at the most", where they came to rest in "some sort of backwater or river lake -- possibly a great meander, or an oxbow lake;" (4) "The mass of bones was soon buried by the sands and silts dropped by the reborn river, and by wind-carried debris swept off the parched land."

There is no unequivocal evidence for drought provided by the skeletons in the Agate bone bed. The number of animals alone is not sufficient to prove this, since we know from recent ecological studies of the Serengeti ungulates that mass drownings, lack of sufficient food proportional to the standing population, and malnutrition/disease also could produce such mass deaths. It is possible to have normal rainfall and grass growth, for example, and if the present population exceeds their food resources, to have mass death through lack of food. To invoke drought here is to go beyond the available evidence.

It is not true that mixed with the bones of rhinoceros, chalicothere, and entelodont are the remains of "oreodons, cats and dogs" in these quarries. The survey of the sites undertaken here will show that oreodonts and canids are represented by only a few very rare waterworn bones, and are surely attritional specimens of much different origin than the main mass of rhino bones, as Matthew (1923) pointed out. Cats have never been found in the Agate bone bed or in any of the depositional environments of the Upper Harrison in the region. The quarries also have not produced "a variety of equally thirsty smaller animals;" in fact, the fauna is distinguished by its lack of species diversity.

Macdonald is not aware that some bones in the quarries show much abrasion, yet other parts of the bone bed show very little. His claim that the bones did not move more than a few hundred meters, while possible, is not favored by present evidence over a number of other speculative statements that could be made about the distance these skeletons were transported. It is possible that the attritional bone accumulation in University Quarry includes bone transported over distances much greater than a few hundred meters, but it is difficult to distinguish bone that has been abraded during travel over a long distance from bone that has been abraded without transport, for example as bedload material confined to a pothole or depression in the channel bed. At Agate, with its deep grooves and channels, reported by the early excavators of the bone bed, this latter possibility is far from improbable. I have observed a number of bones in various museums which are strongly abraded on one side but not on the other, suggesting to me a long term stable orientation of the bone in a groove or hole. Periodic oscillation of the bone in such a confined depression abrades only the side in contact with the sandy bed, yet actual transport distance is nonexistent.

The same problem that faced Matthew in arguing for death in quicksand plagues Macdonald in his argument for drought as the primary cause of death. There is presently no known evidence from the bone bed that points directly to drought or to quicksand in opposition to other forms of mass death. Moreover, the presence of only three species of mammals in the bone bed is difficult to explain in both the quicksand and drought hypotheses, because these are nonselective agencies that should kill any animal that comes within their sphere of influence.

Our studies of the kinds of fossil mammals found in other Upper Harrison stream deposits in the region help to explain the low species diversity in the Agate bone bed. In these ephemeral stream deposits, we find that particular mammals are nearly always found: chalicothere, entelodont, a large bear-like amphicyonid carnivore; less frequently, 3-toed horses. If we look at their skeletal anatomy, we see indications that these mammals probably required brushy cover of the kind that might be found along the stream courses. They would not have fared well in open country. For example, the teeth of chalicotheres suggest a browsing diet, and the skeletal structure of their feet indicates little rapid locomotor facility; the large bear-like carnivore would have possessed a rambling gait like a modern black bear (Hunt, 1972, Ysengrinia), and was *not* a swift open country runner; the feet of entelodonts are not as advanced as those of ruminant artiodactyls, lacking keeled ridges on the bones of the feet for efficient fore-aft motion; entelodont teeth indicate not a diet of open-country grasses but succulent plants, roots and tubers, browse, and perhaps carrion, which these mammals might easily encounter along stream margins.

Against this background, the small rhinoceros seems incongruous, for it has developed moderately high crowned teeth that could be effective in grazing, has a skeleton that suggests an efficient long-limbed runner, and apparently existed in herds. It is not the type of animal to be found in the brushy vegetation along ephemeral waterways, but seems a creature of the open plains. Yet its incongruity is the very element that suggests a plausible scenario.

If the Arikaree tableland in early Miocene time was subject to seasonal climate, and Menoceras herds migrated north and south over the plains east of the mountain uplifts to follow the seasonally available vegetation, it is only when they crossed swollen streams in the wet season that their 'fossilization potential' would be particularly good. At other times of the year, they would form part of the open plains attritional accumulation, and indeed, such Menoceras fossils in the form of single individuals are encountered in the interchannel facies of the Upper Harrison. If these rhinoceros herds, however, suffered mass drownings on occasion when crossing flooded streams, we would expect to find them entombed with the regular inhabitants of these ephemeral stream valleys, such as chalicotheres and entelodonts. At Agate, chalicothere and entelodont, the common inhabitants of the stream valleys east of the uplifts, are buried together with a great mass of plains rhinoceros. An unknown death event led to the accumulation of many rhinoceros carcasses; this death event sampled these mammals in great numbers, a situation that seems probable only when the herds were in proximity to the ephemeral drainages of the region. Whether the rhinos were near the stream because of migration or simply because of their need for water we do not know. But their burial together with only species that are common in other ephemeral stream deposits of the Upper Harrison beds in the region suggests a death event directly related to the stream setting. Thus, stream floods seem a reasonable choice at present as the primary cause of death of large numbers of mammals of a single species, and also are probably responsible (as a series of periodic seasonally-restricted flood events) for the eventual concentration of bones at the site. As field work at the Agate quarries continues, new evidence will undoubtedly modify and eventually clarify this preliminary scenario, and contribute to a better understanding of the origin of the bone bed in the main Agate hills.

3. THE EARLY EXCAVATIONS AT AGATE

3.1. Conflict and Competition: 1904 - 1908

The first five field seasons of 1904 through 1908 were the time of greatest interest and activity at Agate. Field parties from major museums and universities vigorously competed for an opportunity to excavate at key sites in the main hills. A detailed correspondence among the Cook family, Peterson and Holland at the Carnegie Museum, Barbour at the University of Nebraska, and Osborn and Matthew at the American Museum, records the historic development of access to the various sites. This correspondence, supplemented by field diaries, notes, and maps, is brought together here to decipher the sequence of events surrounding the competition for Agate's fossil reserves.

Personal and institutional ambitions thinly disguised under the rubric of scientific priority and propriety guide the actors in this paleontological drama. Almost inadvertently, the Cook family prolongs the play by bringing more actors on the stage: Peterson is hardly on the ground in early 1905, when Harold Cook invites Barbour to avail himself of part of this fossil bonanza. Later, in 1906, James Cook encourages H. F. Osborn to excavate at Agate, a step that precipitated direct conflict between the American and Carnegie paleontologists. One of James Cook's letters records his desire to see the great quarries worked out in his lifetime. From Cook's perspective, the bringing of several institutions into the Agate fossil bed was an honest attempt to achieve what to him must have seemed a sensible goal, the sharing of these paleontological riches among a variety of museums. But the ambitions of the competing scientists thwarted so simple a plan, and resulted in a complex interplay of events that dispersed the fossils and critical field data to the collections and records of diverse institutions, much of it not to be carefully compared and analyzed until the present day.

The principal excavations are summarized in Appendix A. For each site, the following information is provided:

(1) year of excavation
(2) expedition leader and institutional affiliation
(3) location and geographic extent of excavation
(4) listing of fossils from the site
(5) present location of fossils from the site
(6) methods employed in excavation of fossils

The information in Appendix A is further amplified below (pp. 51-153), where a fuller account of the historical development of these excavations is provided in order to adequately document the scientific history of the national monument.

3.1.1. 1904 Excavation

In 1904, O. A. Peterson and his assistants, T. F. Olcott and A. A. Dodd, were the only party to work the main Agate hills. Peterson's initial discovery of the bones has been discussed in Section 1.1 and will not be reviewed here.

Quarry A

The only site to be worked in 1904 was Quarry A (Fig. 3.1) of the Carnegie Museum, today a 25' x 37' southwest-facing shallow depression littered with bone fragments that are scattered over the approximately 900 square feet of surface. Quarry A is situated at the north end of a low ridge extending northwest from University Hill: the ridge is separated from University Hill by a grassed saddle about 400 feet in northwest to southeast extent. I have named the low ridge containing the old site of Quarry A the North Ridge, so that each of the four topographic highs in which quarries were excavated at the main Agate hills will have an identifying name: Carnegie Hill, University Hill, Beardog Hill, North Ridge (see Map A).

No early photographs of Quarry A show a close view of the site or active excavations by field workers. However, several distant views of the quarry were published by Peterson (1909, Fig. 24; 1910, Fig. 1). When compared with the later misoriented map by W. J. Holland (this report, Map C; Holland and Peterson, 1914, Fig. 1, site A), and the more accurate map of Harold Cook (see Map B, this report), both of which show the location of Quarry A, there can be no doubt that the site was situated at the north end of North Ridge. My field study of North Ridge indicates the presence of only a single area where any bone fragments occur on the surface of the ground; this area with its dense concentration of fragmentary bone has been inferred to be the location of Quarry A (Fig. 3.2). It is this area that is mapped as Quarry A on Map A.

At least one other paleontologist later excavated at Quarry A, other than Peterson and his men. F. B. Loomis of Amherst College worked the site, but no record survives today in the form of field notes or plainly marked fossils in the Amherst collection. The only museum with fossils that are certainly from Quarry A is the Carnegie Museum in Pittsburgh, and only Peterson in his publications comments on his work at the site.

Six kinds of mammals are known from Quarry A, based on fossils in the Carnegie collections. Over 95% of the bones belong to rhinocerotids, but an equid, a camelid, an entelodont, and an oreodont are each represented in the fauna by a single bone. No carnivores are known. The rhinoceroses are represented by two species: (1) the small running rhinoceros, *Menoceras*, which is the common rhino in the main Agate hills; (2) the larger heavy-bodied rhinoceros, *Diceratherium niobrarense*, which is very rare in the main hills. Here in Quarry A, the situation is reversed, for Menoceras is quite rare, while true Diceratherium makes up most of the bones from the quarry, including a superb skull (CM 1271) that served as Peterson's type specimen.

Although I could find no chalicothere bones from Quarry A during my survey of the Carnegie Museum collection, a field label in Peterson's hand notes "various foot bones" of the chalicothere Moropus (CM 1914) found at Quarry A on August 8, 1904. The word "cancelled" has been written across this field label, but no reason for this is given. Thus the status of chalicothere in the quarry is uncertain.

The minimum number of individuals of Diceratherium niobrarense that are present in Quarry A, based on the bones that can be certainly attributed to the quarry, is three adults and one juvenile. This is based on 3 left metatarsals of adults, and on rare remains of a juvenile (including a right lower jaw and 2 femora). No more than one individual of Menoceras is indicated by a partial rostrum, lower jaw, and 2 femora of an old male. About 33 additional bones, an adult upper and lower jaw, and 2 juvenile lower jaws could also have been found in Quarry A, but there is no data marked on these bones to confirm this. A number of these bones show a light orange patina seen on many Quarry A fossils, but I have not included them in the count to determine a minimum number of individuals. All of these uncertainly allocated bones belong to true Diceratherium. If these bones were added to the bones definitely known to come from Quarry A, they increase the number of adult Diceratherium to four, and the number of juveniles to two, so the total number of individuals contributing to the Quarry A rhinoceros sample need not be large.

Thus, based on the Carnegie Museum Quarry A sample, the skeletons of 11 mammals could account for the known remains: 7 rhinoceros (4 adult Diceratherium, 2 juvenile Diceratherium, 1 adult Menoceras), 1 equid, 1 camelid, 1 oreodont, and 1 entelodont. Mammals represented by a single bone in the quarry probably never were present as partial or complete skeletons. These are isolated bones left after the scattering of the skeleton by taphonomic processes. Because of the many bones of true Diceratherium, it would be useful to know the environment of deposition of Quarry A, but such a study has not yet been completed.

The Agate Ash

Immediately south of Quarry A on North Ridge are two outcrops of white calcareous ash (see Map A) that, if traced 100 feet north to the quarry, would directly overlie it. These ash outcrops belong to a single ash bed that occurs both north and south of the Niobrara River within monument boundaries, and has been called informally the Agate Ash by Skinner et al. (1977, p. 291). The Agate Ash was dated by the potassium-argon method using the mineral biotite, yielding a

Property of
Agate Fossil Beds National Monument

Fig. 3.1. Carnegie Hill (far right), University Hill (center), and North Ridge (left), looking east, photographed in 1912 by Albert Thomson. Arrow indicates the location of Carnegie Quarry A, the first excavation opened in the Agate hills in 1904.

Fig. 3.2. Quarry A of the Carnegie Museum, at the north end of North Ridge, photographed in 1975, looking north to the national monument headquarters (upper left) across the valley of the Niobrara River. Bone fragments cover the ground surface at the north end of the depression, marking the presumed location of the first of O.A. Peterson's Agate quarries. Peterson was brought to this site by Harold Cook in early August 1904.

Fig. 3.3. The Agate Ash, a laminated white water-laid vitric tuff, occurs within the Harrison Formation throughout the eastern part of the national monument. A particularly thick outcrop of the ash (indicated by arrow) is exposed on the north side of the Niobrara River valley on the road leading to monument headquarters from Nebraska highway 29. A sample taken from this outcrop has been dated by the potassium-argon method at 21.3 million years by University of California-Berkeley geologists in 1964.

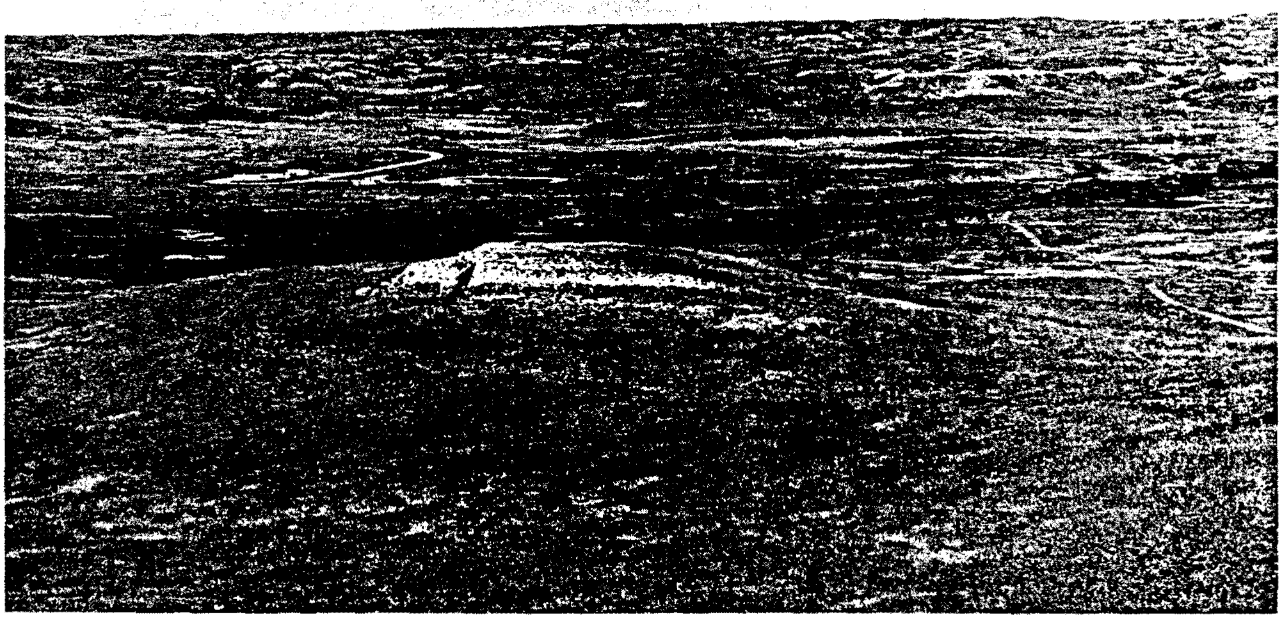


Fig. 3.4. The Agate Ash (arrow marks south outcrop) as exposed on North Ridge (see Map A) with the Niobrara River and monument headquarters in the distance to the north.

within the Harrison Formation. (The main Agate quarries in University and Carnegie hills occur in the base of the Upper Harrison beds.) There is no evidence that they occur 30' stratigraphically above the Agate Ash; in fact, mapping of the area (Map K) demonstrated that no outcrop of the Agate Ash occurs in proximity to either Stenomylus Quarry or Syndyoceras Quarry. At present, I believe on the basis of the stratigraphic position of these two quarries within the Harrison Formation that Stenomylus Quarry probably occurs below the ash, and Syndyoceras Quarry occurs 44 to 64 feet below the Harrison-Upper Harrison contact, thus almost surely below the ash.

3.1.2. 1905 Excavations

Only two parties worked in the main Agate hills during the field season of 1905. The Carnegie Museum arrived first, working from April through early October (Oct. 4 is the latest dated field label), opening Carnegie Museum Quarries 1 and 3. The University of Nebraska arrived in mid-July and left Agate on August 31st, opening only one excavation, the University Quarry on University Hill.

Peterson and Barbour, although in charge of the Carnegie and Nebraska crews, were absent from the sites much of the field season.

Carnegie Quarry 1

The Carnegie party arrived at Agate in April, and included Peterson and T.F. Olcott. Peterson (1909, p. 73) described their new effort:

> "Early in the spring of 1905 the writer accompanied by Mr. T. F. Olcott resumed work in quarry No. 1 .... Mr. Cook impelled by curiosity had already started in the previous fall to excavate in quarry No. 1 ..., but after earnest entreaty by letter to await the coming of more expert help desisted from his work. Many piles of fragments were found on the edge of the opening which had been dug out by Mr. Cook. These fragments were carefully gathered and packed before the commencement of systematic excavations. The work being fairly started, Mr. Olcott was left in charge of the quarry, while I returned to Pittsburgh in order to attend to other duties in the museum. Thus was started one of the most important fossil quarries ever found in North America.
>
> "When I again returned to the field later in the season, Mr. Olcott was still engaged in the same hill, while Professor E. H. Barbour ... had been invited by Mr. Cook to open a quarry in the adjoining hill .... Much material had been uncovered in quarry No. 1 among which the most important were bones of Moropus, many individuals of [Menoceras] and an unusually well preserved, and pretty nearly articulated

skeleton of a gigantic Entelodont [Dinohyus] .... One hind limb and most of the parts of the skeleton anterior to the pelvis were recovered. The pelvis, the lumbar vertebrae, and perhaps also one hind limb were unfortunately dug out by Mr. Cook and those assisting him and only portions of four vertebrae and the pubic symphysis of the pelvis were recovered from the fragments left on the edge of the quarry."

Olcott worked from April until July in Quarry 1 on Carnegie Hill. Peterson in the company of A. J. Hermann apparently arrived at Agate in the latter part of July: the earliest field label listing Peterson as collector in mid-summer is dated July 28. In 1906, in his paper on the work at Quarry 1, Peterson described his field crew of 1905:

> "From the line of Mr. Cook's exploration the excavations and work were carried on by Mr. T. F. Olcott from April until July, when the writer accompanied by Dr. J. A. Hermann again joined the party, and continued work with it during the remainder of the season of 1905. Toward the latter part of the season Mr. W.H. Utterback also joined us ...."

Peterson (1906, p. 488f, Plate 21) published a good description of the extent and location of Quarry 1, and also a plan map of the blocks of fossil material taken from the site, including detailed placement of important specimens such as the large entelodont (CM 1594):

> "During the season of 1905 the party uncovered an area of 45 x 20 feet in the quarry. This area was plotted out in squares five feet in dimension, and a diagram [see Map D] was made representing this arrangement. The bones are found mostly disarticulated, much mixed, and thickly distributed through this layer of sandstone. It was soon discovered that the most intelligent way in which to secure this tangled mass of material was to take out blocks of sandstone which contain the fossils. On the diagram the more important specimens are always indicated, as are the areas in the quarry where the bones are less abundant, and the numbers correspond to every package."

By comparison of Peterson's 1905 map of Quarry 1 with his field notes and box list (a listing of fossils contained within each large box shipped by rail to the museum at the end of the field season), the following summary of the kinds of mammals and their distribution in the quarry was compiled.

Four kinds of mammals were reported: (1) chalicothere, (2) rhinoceros, (3) entelodont, (4) carnivore.

In Map D, the Carnegie Quarry 1 of 1905 is divided into three areas: Cook's excavation of 1904, Olcott's excavation, and the final excavation by the entire Carnegie party (Peterson, Hermann, Olcott, and probably Utterback). This entire area produced numerous Menoceras bones, a nearly articulated Dinohyus skeleton (CM 1594) now mounted at the Carnegie Museum, and part of the skeleton of a large Moropus (CM 1604). The entelodont and chalicothere skeletons are found with many of the bones little removed from their life relationships. Initially, prior to Cook's unfortunate uprooting of the hind quarters, the entelodont was probably a nearly complete skeleton, and was found in a single location at the edge of the quarry. On the other hand, the chalicothere was found primarily in two areas at the site; the skull, jaws and fore quarters were separated from the hind end.

Peterson observed that disarticulated bones of the rhinoceros Menoceras made up the bulk of the deposit in the 1905 quarry. There were at least 16-17 individual Menoceras present, based on a count of confirmed skulls in Peterson's 1905 field notebook. However, Peterson (1906) later reported 50 to 60 skulls from the season's work in the quarry. A few rare fragments of carnivores from Quarry 1 are listed in Peterson's 1905 notes but are not specifically identified. Fossils were removed from about 475 square feet of working surface in 1905.

The fossils excavated by the Carnegie party in 1905 represent the most southern sample from the main hills for which we have information on bone orientation and distribution. The American Museum Quarry of 1923 is farther south (see Map A, South Excavation), but no data on bone distribution at that site has survived. The 1905 Carnegie Quarry 1 has certain features in common with other sites in the main hills: (1) predominance of rhino, with most skeletons disarticulated; (2) rhino, chalicothere, and entelodont the common species, with other mammals represented only by rare and fragmentary bones; (3) tendency for some chalicothere and entelodont to be partially articulated or to have the bones closely associated in the deposit; (4) some bones in the lower part of the bone bed heavily worn and abraded, while other bones are untouched by abrasion. Regrettably, although he mapped the pattern of his fossil blocks in the quarry, Peterson did not photograph or map the bones themselves within the blocks during laboratory preparation of the material. Only Block 90, a large slab with many rhinoceros bones, was later illustrated in his quarry map of 1909 in any detail, and this accompanied rather detailed mapping of the entelodont (CM 1594) and chalicothere (CM 1604). But although rhinoceros bone must have made up most of the remaining blocks from the quarry, no record of the kind and orientation of these bones apparently was ever made.

The only photographs of the 1905 Carnegie excavation appear in Peterson's first published study of the quarry (see Peterson, 1906, Figs. 1, 2, 3).

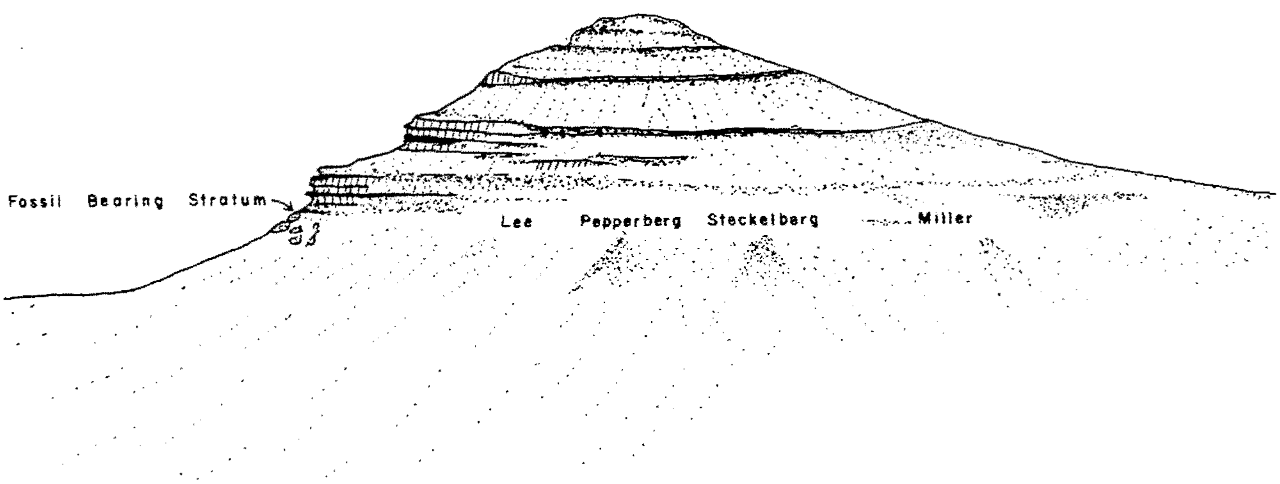


Fig. 3.5. West face of University Hill sketched by Leon Pepperberg during the 1905 excavation of University Quarry. Pepperberg indicated the area in the quarry worked by each member of the field party.

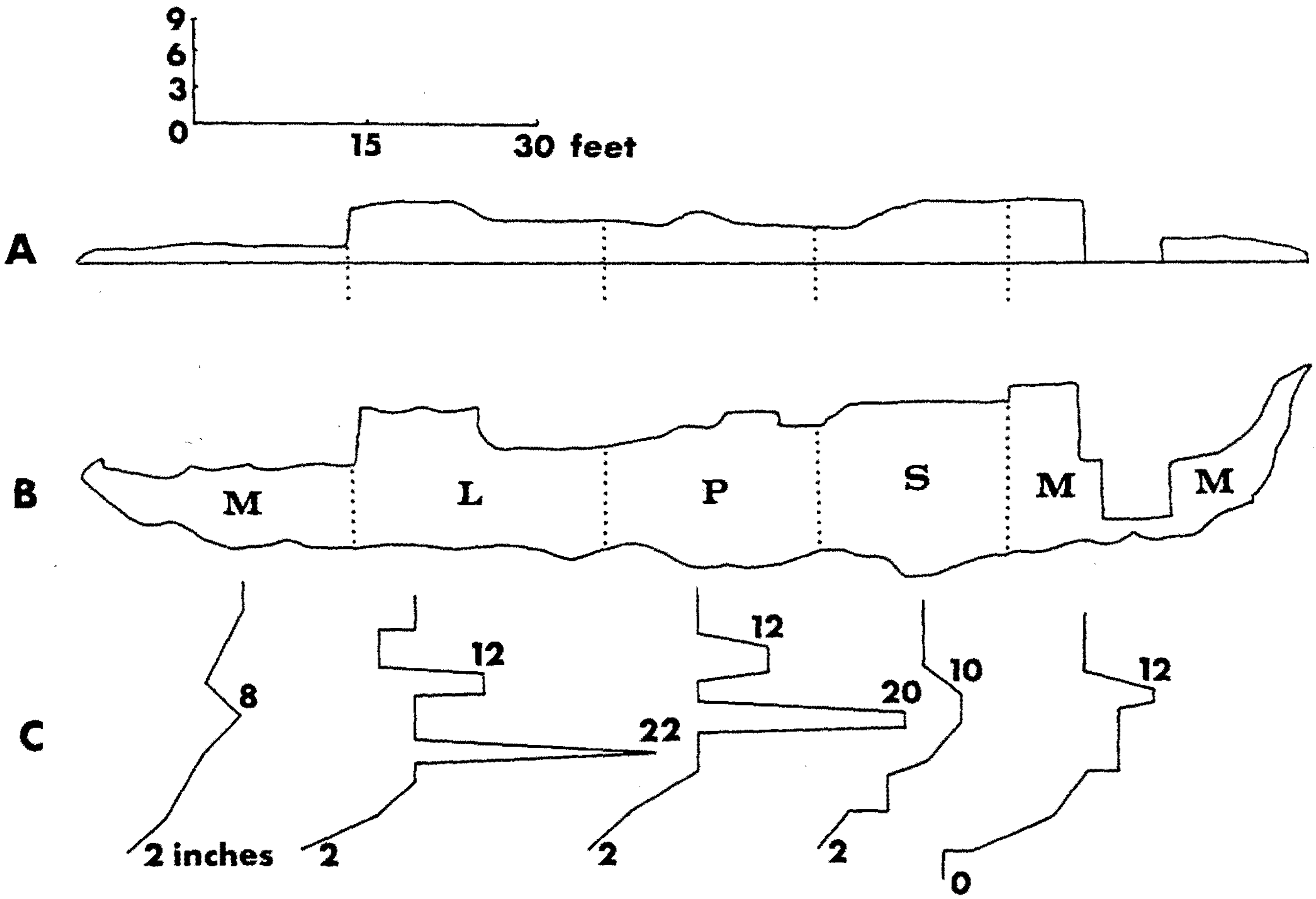


Fig. 3.6. (A) Height of face of University Quarry at end of 1905 excavation (north end of quarry at left); (B) Area of floor of University Quarry at end of 1905 excavation (scale in both A and B in feet); (C) Thickness of bone layer in University Quarry as plotted at end of 1905 excavation (scale in inches). Quarry area worked by each man indicated by his initial: M, Miller; L, Lee; P, Pepperberg; S, Steckelberg. Plot of bone layer thickness was presumably taken perpendicular to quarry face, but this is not certainly stated in Pepperberg's field notes.

University Quarry

In May 1905, Harold Cook notified E. H. Barbour of the University of Nebraska of the great fossil discovery at Agate, encouraging him to develop his own site. By the end of June, Barbour had not been able to find time to visit Agate. But between June 29 and July 9, he made a brief visit to the Cook ranch to estimate the value of excavations. Undoubtedly impressed by what he had seen, Barbour on his return to Lincoln immediately wrote Harold Cook that he was coming to open a site for the university, and on July 13th, Barbour and four men left Lincoln for Agate. The 1905 party included Leon J. Pepperberg, Montrose L. Lee, John H. Miller, and William D.J. Steckelberg. They reached Agate on July 17th, and began the first excavation into the west face of University Hill (as Barbour named it) on July 20th. Fossils found in 1905 by the University of Nebraska party were all given the suffix 20-7-05 in reference to this starting date.

Pepperberg served as leader in Barbour's absence, keeping a fairly detailed field diary that remains the best record of the 1905 expedition (the diary is preserved in the University of Nebraska State Museum archives). Pepperberg was careful to illustrate the quarry floor plan, the depth of the bone layer, the areas where the different crew members were assigned, and a general sketch of the west side of the hill (see Figs. 3.5-3.6).

On July 20th, the day that digging began, Pepperberg wrote: "Stripped 50 feet in bone layer .... This quarry is No. 20-7-05 .... Q. 20-7-05 is divided equally to L, P, S, M, [last initial of each of the crew] and specimens so marked." Barbour left for Lincoln the next day (July 21) and did not return until July 27th. Olcott and Peterson visited the Nebraska party during the first week of their work at University Hill. On July 30th, Barbour left Agate and returned to Lincoln, and apparently did not return the remainder of the field season. The Pepperberg party left Agate on August 31st, ending the field season for Nebraska.

In summarizing the 1905 work, Pepperberg wrote in his diary: "The work was continued as per directions until the close of the season, a great number of bones being taken out in a short space of time. Our quarry was not rich in skulls, that is, as far as we have developed it. The few skulls taken out were in bad condition. Toe bones, scapulas, vertebrae, ribs, etc. were plentiful as were also solitary teeth."

Quarry dimensions as left in 1905 at the end of the season were mapped by Pepperberg in his diagrams (see Figs. 3.6A, 3.6B). The quarry was 108 feet long with an average width of 15 feet. The working face of the quarry when excavation had halted was from 6 inches to 5 feet high. The bone layer thickness was from 2 inches to 22 inches in depth with an average of 8 inches, remarkably close to the values reported by Peterson for the Southwest Excavation on Carnegie Hill.

Bone density in parts of the quarry seems to have been low. On August 8th, Miller and Steckelberg who were located at the south end of the quarry ran out of bones. This area today is the place where a channel margin ascends to the south, and indeed bones might be expected to thin out or become more sparsely distributed at the margins of the channel. In agreement with this is Figure 3.6C, showing the thickness of the bone layer. Note that Pepperberg and Lee had the thickest parts of the bone layer wholly within their working areas, which were at the center and north end of the quarry, in the location today known to be the central part of the channel bed.

Mammals found by the crew included rhinoceros, chalicothere, and entelodont. Examination of these fossils at the University of Nebraska State Museum confirms that they represent Menoceras, Moropus, and Dinohyus. The total amount of material found in 1905 is difficult to determine: no summary of the bones was made by either Barbour or Pepperberg. The bones, however, represent the same mammals as found by Peterson at Carnegie Hill, but were more fragmented and scattered.

Carnegie Quarry 3

Quarry 3 is perhaps the most unusual of the Agate Quarries located in the main hills. The quarry (Fig. 3.7) is unique in producing only the bones of carnivorous mammals, primarily the large amphicyonid beardog Daphoenodon superbus. Nearly complete skeletons of Daphoenodon were found by Peterson in Quarry 3, but only very rare bone fragments of herbivores have ever been found at the site. This abundance of fossil carnivore remains stands in marked contrast to the principal quarries at Carnegie and University hills where carnivores are very scarce, and the bone deposit is made up of bones of herbivorous rhinoceros, chalicothere, and entelodont.

The problem was solved in September 1981 when Hunt and Kaufman of the University of Nebraska State Museum reopened Quarry 3. They found that Peterson and his party had unknowingly begun the excavation of a carnivore den complex made up of many large burrows. The burrows contained the bones of carnivores that had died and then been entombed by later sediment influx into the burrow mouths (Hunt, Xue, and Kaufman, 1983). Exploration of Quarry 3 by the University of Nebraska party continued during the field season of 1982, and resulted in the discovery of carnivore skeletons within some of the burrows, leaving no doubt as to the nature of the site.

Once we realized that Quarry 3 had penetrated an Early Miocene carnivore den complex, every effort was made to exactly locate Peterson's site and establish its extent. Unfortunately, Peterson

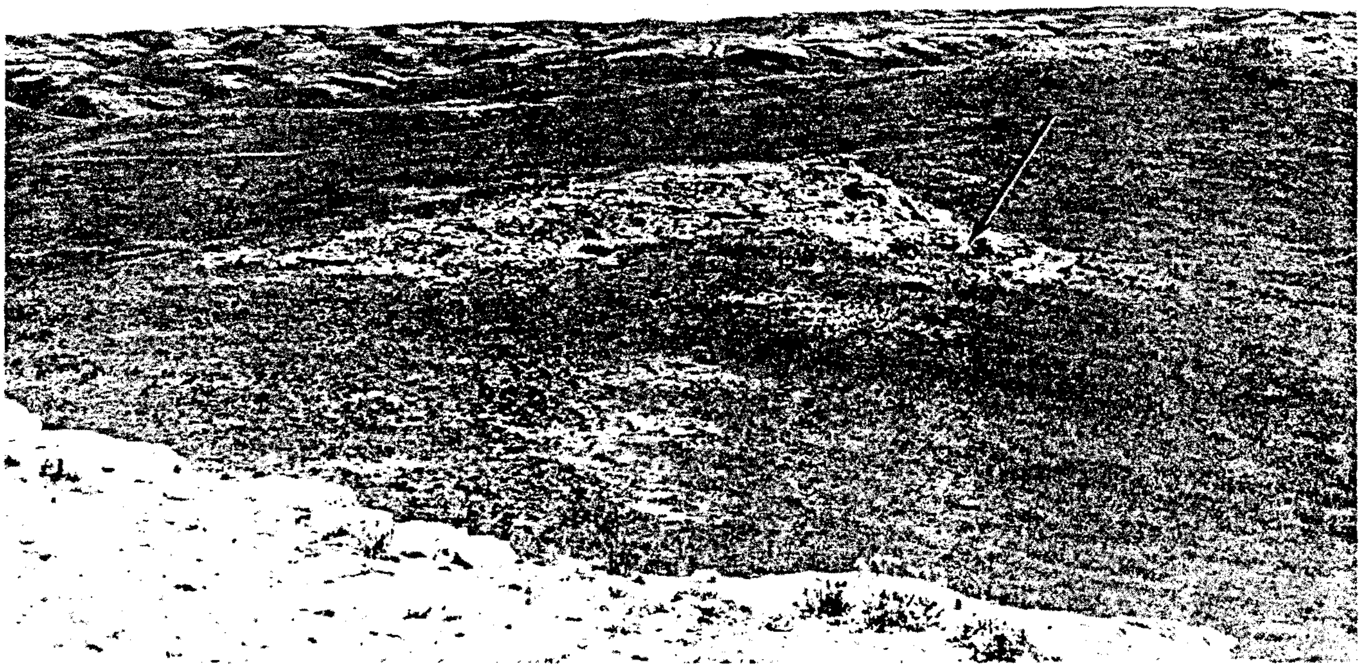


Fig. 3.7. Beardog Hill, Agate National Monument, looking southeast from the top of Carnegie Hill at the location of O.A. Peterson's Quarry 3 of the Carnegie Museum (arrow). The photograph was taken in 1971 ten years before the quarry was relocated by a University of Nebraska field party in September 1981. At this place, an Early Miocene den complex produced the remains of two species of amphicyonid carnivores, a mustelid, and a small canid, at one time all apparent residents of these burrows. The Quarry 3 dens are the oldest known mammal burrows that contained the skeletal remains of large carnivores.

left no photographs or unpublished notes despite a search of archives at the Carnegie Museum in Pittsburgh. However, through published records and careful field work, it has been possible to relocate Quarry 3, and learn something of its early history.

Quarry 3 was apparently discovered in 1904 at the same time as the initial discovery of the bones at Carnegie and University hills. Peterson (1910) described the discovery in a major scientific paper on the carnivores he had found at the site:

> "While prospecting in the layer of fossil bones, which is exposed around 'Carnegie Hill' and 'University Hill' in the Miocene formation on the upper Niobrara River in Sioux County, Nebraska, with a view to opening additional quarries, [Peterson's footnote: No quarries except quarry A had at that time (1904) been opened in these hills.] the writer, assisted by Messrs. T. F. Olcott and A. A. Dodd, was extremely fortunate in finding in what is now called Quarry No. 3 ... various remains of carnivora ...."

The only photographic record of the location of Quarry 3 provided by Peterson was a published figure (Peterson, 1910, Fig. 1) marked with the number 3 on the west side of Beardog Hill. In 1981 we began test excavations on the west side of the hill in an attempt to relocate the site. Two test trenches were placed in the southwest corner of the hill, each extending about 10 feet directly north into the side of the hill at the level of the stratigraphic contact between the Harrison Formation and Upper Harrison beds. No bone or evidence of earlier digging was found. Moving about 20 feet northwest of these trenches, we began to remove the surface soil above the bedrock at the place where a partial humerus of _Daphoenodon_ had been found in 1971 during an earlier reconnaissance of the Quarry 3 area (Hunt, 1972, Fig. 3). After passing the soil through screens at the site, we found a number of fragmentary amphicyonid bones. One of these bones, the proximal end of a tibia (UNSM 10-81), was later fitted perfectly to a small bone fragment that had been collected by Peterson's party in 1905 at Quarry 3. Once the location of Quarry 3 had been established, we continued to remove the surface soil to the level of the bedrock, but did not disturb the bedrock surface. The burrows were revealed intruding into the bedrock as the soil was gradually removed during the 1981-1982 excavations.

Despite Peterson's statement that Quarry 3 was discovered in 1904, there is no record of any fossils from the site bearing that date. The greater part, if not all, of his collection was secured in the field season of 1905. We find evidence of this in Peterson's listing of the contents of boxes sent to the Carnegie Museum in 1905:

> "Bx. 17. Large block containing carnivore skeletons of at least two individuals and may be enough to effect a full

relief restoration of the animal. A package of fragments which go with this specimen is in box 22. The specimen was not found in the Agate Spring quarry, but on the same strike (level) and only 100 yds. to the southeast of the quarry."

This entry directly corresponds to Peterson's published remarks (1910, p. 206) on the discovery of the female type specimen of Daphoenodon superbus, and the smaller juvenile male that was found with her in Quarry 3:

"In the quarry designated as No. 3 ..., there were found from five to nine individuals of Daphoenodon superbus, of which No. 1589 is practically a complete skeleton. The latter was found imbedded together with another individual of the same species not fully adult [CM 1589a]. The soft sandstone in which the two were found was taken out in a large block and transported to the Museum. On examination it was found that the adult individual was partly articulated ...."

So here is proof that the female holotype individual of Daphoenodon was collected as a partly articulated skeleton in 1905 together in the same sandstone block as the male juvenile CM 1589a.

Two other species of carnivores were found in Quarry 3 by Peterson in addition to the sample of Daphoenodon. An upper and lower jaw of a small canid were named by Peterson "Nothocyon" annectens, today referred to the small raccoon-like dog Phlaocyon. A lower jaw and partial skeleton of a small mustelid carnivore were called by Peterson Paroligobunis simplicidens. Proof that the mustelid and canid were definitely found in Quarry 3 is derived from field labels and Peterson's published remarks.

Appendix C presents a summary of known information on the amphicyonids, canid, and mustelid collected by Peterson and his party in Quarry 3. With regard to Phlaocyon annectens, Peterson (1910, p. 206) wrote:

"Besides the type of Nothocyon annectens Peterson and another small carnivore [CM 2389, skeleton of Paroligobunis simplicidens] described later in this paper there was little else found in Quarry No. 3 except remains of Daphoenodon superbus."

As further confirmation that the type specimen of Phlaocyon annectens came from Quarry 3, Peterson (1907, p. 53) wrote:

"The specimen was found associated with the type of Amphicyon superbus ... near the Agate Spring Fossil Quarry, in Sioux County, Nebraska."

We do not know whether the canid came from the same sandstone block as the type of Daphoenodon, or whether it came only from Quarry 3, but use of the term 'associated' is usually indicative of a very close spatial relationship.

In contrast to the small canid, field labels and Peterson's (1910, p. 269) published comments leave no doubt that the mustelid _Paroligobunis simplicidens_ was found in Quarry 3. In fact, a phrase written on a field label suggests that the mustelid also might have been closely associated with the type of _Daphoenodon superbus_:

> "Note = Fragments found in talus below where type of _Amphicyon superbus_ was found."

In addition to the canid and mustelid, a few ungulate bone fragments apparently were found by Peterson in Quarry 3, indicated by a single field label in his handwriting:

> "Department No. 1589e... Ungulates ... Quarry No. 3 ... Collector O.A. Peterson ... Various foot bones and sternebrae found in the talus below where the type of _Amphicyon_ was found."

It is not clear who among the Carnegie men excavated the carnivores at Quarry 3 in 1905; we assume that Peterson, Olcott, Hermann, and possibly Utterback performed the work in both quarries 1 and 3. Most of the field labels are in Peterson's own hand, and Box 17, which contained the female type of _Daphoenodon_ as well as the juvenile male, was the first box completed after Peterson's return to the field in mid-summer. Peterson returned to Agate the last week in July, at least by July 27th, for Pepperberg of the Nebraska party noted a visit by Peterson and his wife to the University of Nebraska Quarry on that day. Thus it seems that Peterson began the excavation of Quarry 3 upon his return to the field in late July 1905, and probably personally supervised this work through the remainder of the field season. That no photographs or quarry diagrams of the excavation have been found is especially unfortunate in light of the recent discovery of the dens at the site.

By July 1982, we had cleared an area of about 600 square feet at Quarry 3, exposing a bedrock surface that could about equal the quarry extent developed by Peterson's party in 1905. This area extends 6 meters northeast-southwest by 9 meters northwest-southeast, or about 20 by 30 feet. The burrows distributed over the bedrock surface within this area all could have been at least partly excavated by the Carnegie group: slope erosion prior to development of the 4-6 inch-thick soil on the bedrock also could explain the exposure of these burrows. So we must be cautious in attributing the bedrock surface entirely to earlier excavators, particularly since we have not observed any concentration of pick gouges or grooves. Peterson's men would have used picks, shovels, and hand tools to carry out their work, much as we do today, and these tools often leave marks in soft sandstone that can survive for many years.

Certain puzzling questions about Quarry 3 remain unanswered: why did Peterson's crew somehow leave at least two amphicyonid skeletons and numerous other carnivore bones in place in burrows at Quarry 3, and why did none of the Carnegie party leave any written record that they were aware of the burrow system? This seems unusual when one considers the detailed mapping of blocks in Quarry 1 by Peterson. Perhaps the urgency of carrying on the work at Carnegie Hill in Quarry 1 diverted their attention from the beardogs and dens of Quarry 3. From 1905 until 1981, no record of any other excavators at Quarry 3 has been found.

3.1.3. 1906 Excavations

Two principal field parties worked the Agate quarries in 1906. The Carnegie Museum was represented by W. H. Utterback, who not only worked in Carnegie Quarry 1, but also opened a second site, Carnegie Quarry 2, on the northwest corner of Carnegie Hill (Northwest Excavation, see Map A). On University Hill, a University of Nebraska party carried on work in their quarry, under the largely absentee direction of E. H. Barbour.

Carnegie Quarry 1

The Carnegie Museum began work in the spring of 1906, long before the University of Nebraska group began their work in mid-July. Utterback had much experience collecting dinosaurs for the museum, and much preferred that type of work. Why he was assigned to Agate, and why Peterson remained in the museum during this field season is not entirely clear, but the arrangement eventually led to conflict between the museum and Utterback, and finally to his resignation in 1908. Utterback's work at Carnegie Hill is discussed in the monograph on the Agate chalicotheres (Holland and Peterson, 1914), not in entirely complimentary terms:

> "In the spring of the year 1906 Mr. W.H. Utterback ... was sent to the locality with special instructions to continue the work of uncovering the fossil-bearing stratum at the point where the investigations made by Mr. Peterson and himself in the preceding year had led to the recovery of the jaws and cervicals of the large specimen of *Moropus*. The search was rewarded by the recovery of the greater part of the skeleton. These remains were found at the spot designated in the map as 'Quarry No. 1' on the western face [actually the southwest face - Holland's sketch map was misoriented] of what Professor Barbour ... has designated as 'Carnegie Hill.' Before, however, attacking the task of recovering the remains of this specimen [CM 1604], Mr. Utterback made extensive excavations on the northern face [actually the northwest corner] of the

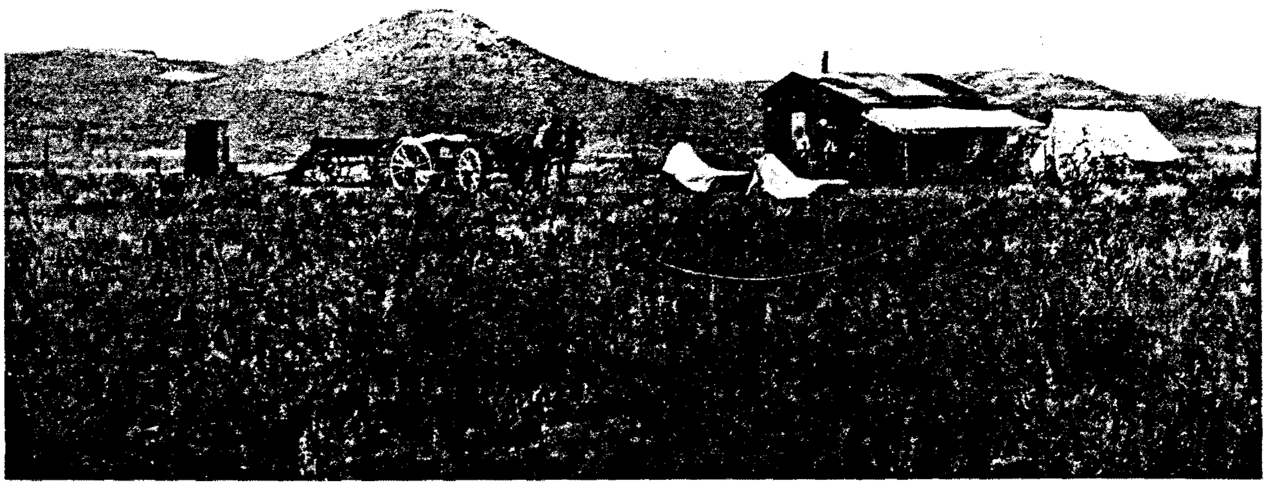


Fig. 3.8. Carnegie Museum camp of W.H. Utterback, during Carnegie Hill excavations of 1906, located on the north side of the Niobrara River north of the main Agate hills near the present monument headquarters.

Fig. 3.9. Carnegie Quarry 1 in the Southwest Excavation (Carnegie Hill) during W.H. Utterback's 1906 excavation. View toward southeast and Beardog Hill; Utterback is second from left. Awning marks work area toward south end of the Southwest Excavation (see Map D).

hill at the point designated ... 'Quarry No. 2.' Here he found a great many bones belonging to the genus Moropus in a disarticulated condition mingled with the remains of other genera....

"In the spring of ... 1908 Mr. O. A. Peterson returned to [Quarry 1], being earnestly requested to make every effort to secure a complete skull of Moropus. With the assistance of ... able workmen he stripped the western side of the butte on which the work of the Carnegie Museum had already been carried on during the three preceding years, beginning near the point in Quarry No. 1 where Mr. Utterback had ceased operations. Although finding an abundance of the fossil remains of other mammals, Mr. Peterson only recovered a few scattered fragments of Moropus. He was on the point of despairing of success in his quest, when, as a last resort, he gave instructions to the workmen to enter the side of the hill at the place where Mr. Utterback had recovered the most of the remains of the large specimen taken up in the fall of 1905 and in the summer of 1906. Mr. Utterback had reported that he had gone into the side of the hill at this spot far enough to satisfy himself that the bone-bearing stratum, to use his expression, had 'played out,' and to all appearances his report was correct.... The men digging under the direction of Mr. Peterson had only gone about two feet into the side of the rock when to the great delight of all parties a nearly complete cranium (No. 2103 ...) of a huge Moropus was discovered. The specimen ... was the most perfect cranium of a chalicothere animal which had thus far been found .... That it is the cranium of the large specimen the remainder of the skeleton of which had been recovered in the fall of 1905 and the summer of 1906 does not admit a particle of doubt. The mandible found by Mr. Peterson in the fall of 1905 exactly fits the cranium discovered in September, 1908. Had Mr. Utterback not reached his conclusion as to the barrenness of the rock so hastily he would have had the pleasure and honor of securing the skull of the animal for the recovery of much of the remains of which in 1906 we are indebted to him."

The labored prose of this account of the Moropus skull discovery surely belongs to Holland, who inadvertently makes evident the tensions that existed among the Carnegie staff following Hatcher's death. Hatcher appears to have served as a buffer between the paleontological staff and Holland's tendency to control all aspects of staff endeavor. With Hatcher gone, Holland was unwilling to appoint a successor, and unable to allow the field men a degree of independence in their decision-making. Gradually frustrations built up, and vigor and efficiency in the field work diminished.

From Quarry 1 in 1906, Utterback recovered 21 boxes of fossils, most bones belonging to the rhinoceros Menoceras, as well as the important skeleton of the large chalicothere Moropus (CM 1604) mentioned in the above narrative. By comparison of Utterback's box list of 1906 with Peterson's plan map of Quarry 1 published in 1909, it is possible to determine the excavation area worked in 1906, as well as its relationship to the areas developed in 1905 and 1908 (Map D). Block numbers are recorded on both the plan map and in the box list, and when plotted on Peterson's map, describe the work area.

The 1906 excavation encompassed about 200 square feet of quarry floor. A west extension of about 100 square feet was developed to the north of Olcott's excavation of 1905, and this area produced chiefly bones of Menoceras. It is separated by a few feet from the east extension, also of about 100 square feet, that contained the greater part of the chalicothere skeleton (CM 1604).

Utterback left no field notes, nor were photographs of the 1906 field work located in the Carnegie archives. However, E. H. Barbour fortunately photographed both Quarry 1 and Quarry 2 in 1906, as well as the Carnegie Museum field camp (Fig. 3.8) north of the Niobrara River (situated at the place where monument headquarters is presently located). A single photograph (UNSM No. 3-19-8-06E.H.B.) indicates that Utterback's Quarry 1 work was carried out as plotted in Map D. Barbour's photograph (Fig. 3.9) shows the awning above the work area placed toward the southeast end of the quarry in the general area indicated on the Peterson (1909, Pl. 54) map.

Fossils found by Utterback in Quarry 1 include numerous bones of the rhinoceros Menoceras, the skeleton of the large chalicothere Moropus (CM 1604), a few other rare chalicothere bones, all referrable to Moropus, and possibly the maxilla of a single individual of Parahippus (CM 1598). The horse is doubtfully from the quarry as one field label for the specimen reads "Agate Spr. Quar. No. 2", and yet the same label bears the Accession No. 3082 which is the number for Quarry 1.

Utterback's collection from Quarry 1 is maintained at the Carnegie Museum, Pittsburgh; some correspondence between museum personnel and Utterback is also present in the Carnegie archives, but nothing dealing specifically with the work of 1906 is available.

It is possible that carnivores are represented by amphicyonid metapodials (CM 1599) in Utterback's 1906 Quarry 1. The field label for this number reads: "Amphicyon ... Sept. 1906, Department No. 1599, Agate Spr. Quarry Sioux Co., Neb., Collector, W. H. Utterback, metapodials." Although the designation 'Agate Spring Quarry' could also mean the specimen came from Quarry 2, the Parahippus maxilla mentioned earlier, numbered CM 1598, carries an accession number indicating Quarry 1, suggesting that the two numbers 1598 and 1599 might have been collected together at about the same time.

Carnegie Quarry 2

Quarry 2 is located on the northwest corner of Carnegie Hill; the old Carnegie quarry is nearly identical in its dimensions to the present Northwest Excavation (see Map A). Today the quarry floor is about 75 feet long and ranges from 10 to 25 feet in width. Although no written record of the Quarry 2 excavation survives, Holland and Peterson (1914) imply that work at Carnegie Hill began at Quarry 1, Quarry 2 then was opened, and the season concluded with a return to Quarry 1. This is also suggested by the box numbers which begin in Quarry 1, then shift to Quarry 2, then return again to Quarry 1. We know that Utterback had begun work in Quarry 2 by June 10th, based on a comment by Harold Cook in a letter to Pepperberg of that date:

> "The bones which Mr. Utterback is taking out are simply great. He has opened a new quarry on the side of the hill next to the University quarry."

When you stand at Quarry 2, you can see University Quarry on University Hill to the northeast, and Quarry A on North Ridge to the northwest. When standing at Quarry 1, University Quarry cannot be seen. This strongly suggests that Quarry 2 is the Northwest Excavation on Carnegie Hill, but proof is provided by the following photographic evidence.

Only two photographs survive of Quarry 2 taken at the time of Utterback's excavation in 1906. Both were taken by Barbour on August 27, 1906 (UNSM Nos. 5-27-8-06 and 6-27-8-06). Comparison of these two photos (Figs. 3.10A,B) with the present quarry shows that the site is nearly identical in dimensions to the original quarry, and has been hardly disturbed at all during the intervening years. Figure 3.10A looks almost directly south, and shows the widest part of the cut at the south end of the quarry. Figure 3.10B looks northeast toward University Quarry and shows the narrowing of the quarry cut toward the north end of the site. Section numbers appear in these photos painted on the walls of the quarry, which suggests that a map may have been made to record the positions of bones as they were removed. These section numbers increase from south to north, indicating that digging probably began at the south end of the quarry and progressed to the north and east. The quarry floor is clean in these photographs, and the walls of the quarry are nearly in the same positions as one finds them today: thus the excavation was probably finished at the time the pictures were taken, so it seems likely that work in Quarry 2 concluded by the end of August 1906.

Fossil mammals found in Quarry 2 in 1906 are primarily bones of the chalicothere Moropus. Field labels in the archives of the Carnegie Museum for the year 1906 almost all pertain to Quarry 2. Using these labels, the list of animals found in the quarry was compiled as Appendix D. Although this listing is probably not complete, it gives an idea of the relative proportion of the different kinds of animals found. In addition to chalicotheres, Quarry 2 has produced bones of Menoceras, an amphicyonid carnivore (CM 1824, an astragalus), a small moschid or hypertragulid 'deer' (CM 1826, astragalus), a non-stenomyline camel (CM 1825, astragalus), an entelodont (CM 1827, incisor), and a long-shanked eagle (CM 1828, tarsometatarsus).

Bones in the quarry are scattered and disarticulated (Holland and Peterson, 1914, p. 192):

> "[In Quarry 2, Utterback] found a great many bones belonging to ... Moropus in a disarticulated condition mingled with the remains of other genera. Although these bones were scattered, they have proved of great value ...."

An attempt to estimate the minimum number of individuals of Moropus present in Quarry 2 can be based on the number of scapulae and lower jaws. The presence of seven left scapulae ranging in size from small through medium to large indicate definite size variation, and at least seven individuals. However, the lower jaws indicate an even larger number of individuals in the quarry, and, based on the eruption stage of the teeth, also tell us the age structure of the sample. On the basis of these jaws, a minimum number of thirteen chalicotheres is present, including at least 8 individuals in which the last lower molar (M3) either is unerupted, or if erupting, is still unworn. Nine chalicotheres of this sample could be termed young or middle-aged, two can be called old, and only one aged individual is present. One specimen is indeterminate. These data will be discussed in a subsequent study on the taphonomy of the bone deposits in the various quarries.

Fossils from Utterback's work in Quarry 2 are housed at the Carnegie Museum, Pittsburgh; unfortunately, no quarry maps or diagrams seem to have survived that record the original placement of these fossils at the site.

The full extent of Quarry 2 is revealed in two photographs taken in 1907 and in 1911 by Albert (Bill) Thomson of the American Museum during work by their party at Carnegie Hill. Quarry 2 is essentially untouched since Barbour's photographs of 1906, corresponding in its extent to today's cut. Thomson's photographs appear in this report as Figure 3.10C (1907, AMNH No. 1090/18333), and Figure 3.11 (1911, AMNH No. 1408/18519).

Quarry A (North Ridge)

The only evidence that Quarry A might have been worked in 1906 is found in a discussion of the fossil collecting history at Agate by Margaret C. Cook, published in 1964 in a brochure advocating the

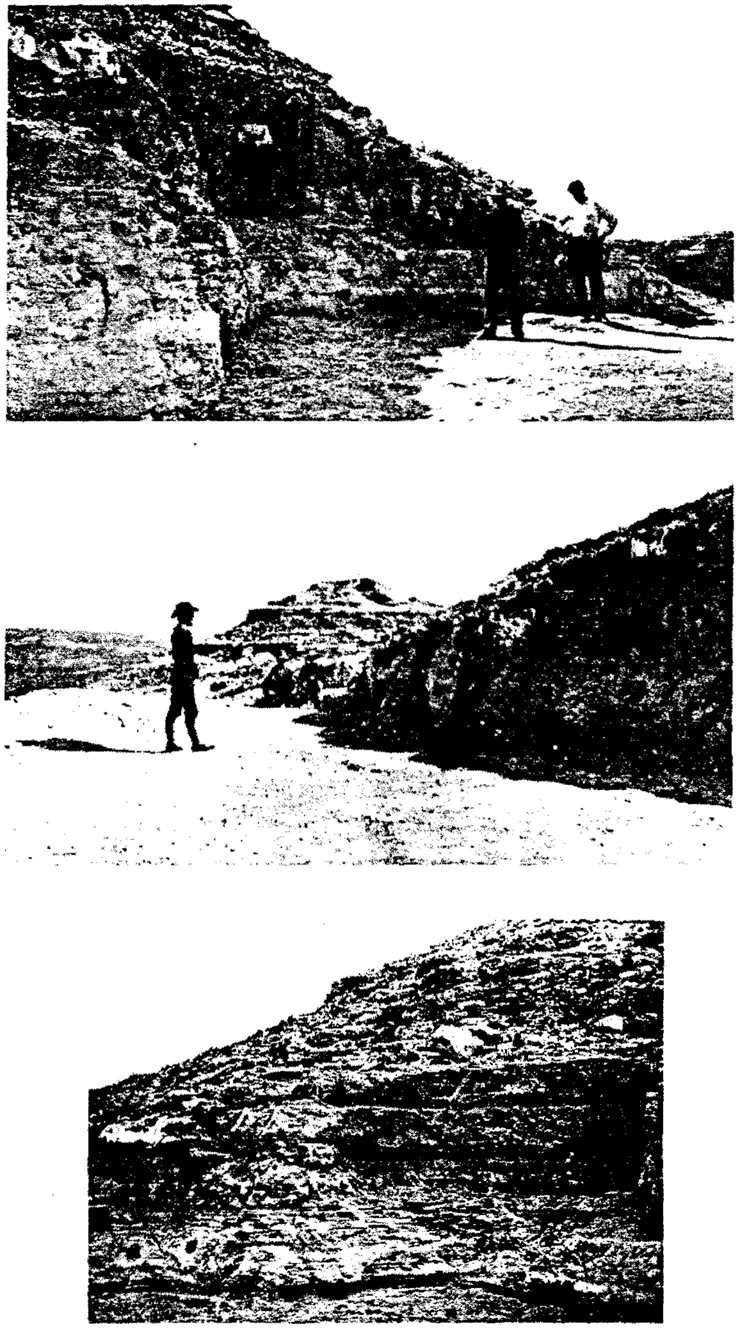


Fig. 3.10. (A) Carnegie Quarry 2 during excavation by W.H. Utterback in 1906, showing Utterback (second from right) at the south end of the quarry; (B) Carnegie Quarry 2 during excavation by W.H. Utterback in 1906, showing north end of quarry, with University Hill in background; (C) Albert Thomson's photograph of Carnegie Quarry 2 as it appeared in 1907, about one year after Utterback's excavation. Note section numbers on the quarry wall presumably used by the Carnegie party to map their fossil discoveries.

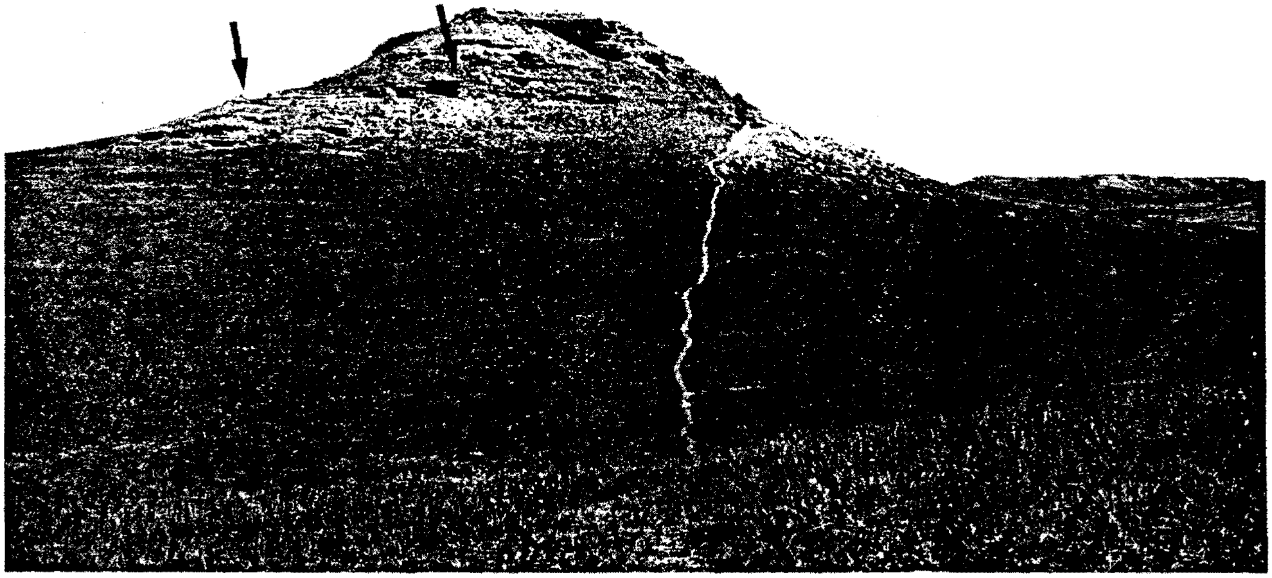


Fig. 3.11. Carnegie Quarry 2 (Northwest Excavation) in 1911 about five years after the end of Utterback's excavation at the site; no extension of the site has taken place. This photograph of the west side of Carnegie Hill was made by Albert Thomson. Arrows indicate the northern and southern limits of Quarry 2; these boundaries are unchanged today.

creation of the national monument:

> "In 1906, Professor F. B. Loomis of Amherst College, an early, able and active paleontologist, joined the collectors with a good-sized party of advanced students. They collected in a small hill which turned out to be a comparatively minor deposit, which Loomis called Amherst Point."

Loomis himself left no field notes of his work at Agate. Despite a careful search in the paleontological collections at Amherst, and in the college library where photographs and memorabilia of Loomis are kept, I could not locate any detailed information on his several years at Agate. That he did excavate in Quarry A, which seems the most likely site fitting the description of 'Amherst Point', is proven by a note written by Peterson in the Carnegie Museum box list of 1908:

> "Bx. 5. Blk. 8 contains various Dicerathere bones. Many packages from sect. 18 ... and a lower jaw found, in quarry A, in a block of rock on the dump left by Dr. Loomis."

However, the year that Loomis worked Quarry A is uncertain. Since Peterson's Box 5 would have been collected early in the 1908 season, it is unlikely Loomis dug there in 1908. Very likely, Loomis worked Quarry A in either 1906 or 1907. Fortunately, one of Loomis's men, C. K. Blanchard, who was a member of his 1908 party at Agate, was located in 1979 by Dr. Margery Coombs of the University of Massachusetts. Dr. Coombs was able to obtain copies of Mr. Blanchard's field diaries and photographs of the 1908 expedition, and to question him about the work and locations of quarries. Blanchard's diary of the Agate work largely confirms the field diary of R. S. Lull of Yale (see section 3.1.5 on 1908 Yale work at Agate). Blanchard established that no excavation on the North Ridge by the Amherst men took place in 1908, but he did not know details of 1907 work, or if a 1906 excavation had occurred. Interestingly, Blanchard had never heard of 'Amherst Point'.

That Amherst Point really is the same place as Peterson's Quarry A is suggested by J. R. Macdonald in 1980, writing on the excavations at Agate:

> "In 1906 F. B. Loomis of Amherst College, Massachusetts, began to collect at Amherst Point, northwest of the two main hills ...."

The only fossil-producing site northwest of the two main hills is Quarry A. This comment by Macdonald coupled with Peterson's note of 1908 establishes Loomis as an excavator in Quarry A. Noone, however, seems to have realized that Quarry A and Amherst Point are the same site, and fossils from Amherst Point that Loomis may have collected are unmarked in the Amherst paleontological collection. The only fossils that today can be certainly attributed to Quarry A are those collected by Peterson in the Carnegie Museum. This is unfortunate since we now know that Quarry A is stratigraphically lower than the main Agate quarries. The main Agate quarries in the base of Carnegie and University hills are found in the Upper Harrison beds. Quarry A occurs, along with Stenomylus Quarry to the east, in the Harrison Formation. Hopefully, in the future it will be possible to identify specimens that Loomis collected, so that the sparse fauna of Quarry A can be supplemented.

E.S. Riggs and the Field Museum

The Field Museum under the direction of Elmer Riggs made an attempt to work in the Agate hills in 1906 but were not successful. Their presence in the area may have spurred Barbour in Lincoln to get into the field and begin work at University Quarry in 1906. On June 30, 1906, Harold Cook wrote to Barbour as follows:

> "The party from the Field Columbian Museum is at Harrison now, and expects to be out here in the next few days. The party is in charge of Mr. Riggs, ... and Mr. Olcott who was with the Carnegie last year is with them. Of course, Mr. Olcott knows where to look around here, so I don't think you can come out too soon. The Kansas University expects to be here in a short time, also, so the country will be pretty well scoured, I expect."

One can well imagine Barbour's reaction: in two weeks, the Nebraska party was at Agate ready to begin work in their quarry.

Riggs and his men did not excavate in the Agate hills, however; the reason why appears in a letter to John Adams from James Cook on September 1, 1906. Beyond explaining Riggs's fate, the letter provides insight into Cook's perspective on ambitious and contentious bone-diggers:

> "Friend Adams:
>
> Your letter of August 22nd received. I know of your relative Prof. H. F. Osborn very well. And I would be glad to have him come to my home at any time and look at the fossil beds about here. As to his working here, I can only say that these 'Bone hunters' like the old time cow men claim to have 'range rights' and the first one to work in a quarry claims the earth about that spot for a certain number of miles or leagues, I don't know which. Dr. Holland of the Carnegie Museum at Pittsburgh has had a party at work here for three seasons, and I caught ---- for inviting Prof. Barbour of the state university of Nebr to come and get a few bones. Prof Riggs of the Field Museum of Chicago was here for a couple of weeks and was very desirous of doing a little work, but Dr. Holland objected, so he left. There is a lot of material here, and the Carnegie Museum has secured a vast amount of good stuff."

So in 1906 Riggs sought good stuff elsewhere, and indeed did quite well. Riggs and Olcott collected in the upper Arikaree rocks to the north and west of Agate, and discovered the holotypes of the carnivores Promartes and Zodiolestes, both found within the helical rodent burrows called 'devil's corkscrews'. Since the discovery of these two individuals in 1906, the former a mustelid, the latter a procyonid, no other carnivores have ever been found within the corkscrew burrows of the region, despite examination of hundreds of these rodent burrow fills and discovery of many specimens of the rodent Palaeocastor within them. The field association of this rodent, believed responsible for digging the burrows, and one of the carnivores is recorded by Riggs (1942, p. 71):

> "The holotype [of Promartes] ... was collected by Mr. T. F. Olcott, who was a member of a Museum expedition to Nebraska and Wyoming in 1906. An interesting feature of the occurrence was that it was found in association with the jaws of a species of Palaeocastor and embedded in the body of a horizontal branch of a Daimonelix in situ. The two specimens were recorded by the collector as 'carnivore and rodent.' When the collection was being prepared in the laboratory, the rodent was recognized and the section of the corkscrew with its contents was labeled 'fragmentary rodent' and returned to storage. Many years afterward the carnivore was recognized and prepared."

Riggs was able to similarly document the occurrence of the procyonid Zodiolestes in a corkscrew burrow (Riggs, 1942, p. 100):

> "[Zodiolestes daimonelixensis] was named for the peculiar spiral form Daimonelix, in which the holotype of this species was found embedded. The skeleton was found coiled about in a lifelike position at the middle of the spiral. Clearly this spiral form was, at the time the animal entered, an opening in the sand in which the animal found harborage ...."

Many years earlier, Riggs (1909) had implicated a burrow origin for the corkscrews, supporting Peterson's observations of the summer of 1904, and noted evidence that had been collected on his expedition of 1906:

> "[I have] found remains of five different species of animals associated with the Daemonelix spirals, viz., skulls and skeletons of Steneofiber [=Palaeocastor], skeletons of two genera of carnivora, a jaw of Merychyus, and parts of the skeleton of Oxydactylus. The last was partly without and partly within the spirals and the parts within had apparently been absorbed or eaten away. The other fossils lay completely within the spirals. Photographs of one of the carnivore skeletons [Zodiolestes] [indicate that] the animal appeared to be coiled up in a natural position, as though resting upon a

bed of sand within the cavity. It was concluded that at some stage of their formation these spirals had been open holes ...."

Curiously, the discoverer of the corkscrews, Barbour of Nebraska, never adopted the rodent burrow hypothesis. But, stimulated by Harold Cook, he brought together his field party, and came to Agate in July 1906 to work University Quarry for his second season at the site.

University Quarry

In 1906, Barbour and his party returned to University Quarry (Fig. 3.12) to continue the work of the 1905 season. He did not begin early in the season as Utterback did, but came to Agate only in mid-July. Barbour seemed to require the continual persuasion and urgings of Harold Cook.

Barbour had entertained Harold Cook in Lincoln in the fall of 1905, and supplied him with tools, mounted specimens, and general encouragement. Cook, then just 19 years old, returned Barbour's gestures by collecting for him, and by advising him of others' interest in the fossils at Agate. Barbour replied to Harold Cook's urgings to take to the field with characteristic vigor, and what might be called a muted sense of panic in a letter of June 17th:

"Whatever you do, stand by the state university if you can? Please do not pass anything out to other beggars if you can possibly save the good things for us. Just think, Holland has the magnificent sum of four hundred thousand dollars a year for such work. It is said there will soon be two thousand a day for the work in his hand. Just think of us competing against such odds!

"Help us in every way you can. When will it be agreeable to you to have us come again to resume work in that quarry which promises so well? I am hurrying matters along so as to get off soon now. I am to have a fellow [E. F. Schramm, later to become chairman of the Geology Department, University of Nebraska] from the University of Oklahoma appointed a Fellow in my department. He is a very promising man and I hope to have him take charge of the work when I am not at Agate myself.... I would like to visit the old bone bed soon. Expect to have considerably more time to spend there than I had last year...."

"I asked the Regents to appoint you an assistant and will report to you in the morning what action was taken in the matter. It is a recognition that will do you no harm. I am told they acted favorably but they have not notified me as yet so I do not know just what was done. Would it suit you to have us come the latter part of this month or the first part of next month?... Have I made it plain that we are ready to

Fig. 3.12. University Quarry at University Hill during the 1906 excavation by the University of Nebraska under the direction of E.H. Barbour.

give you a stipend?... Pepperberg will go to Sarpy County to work on material for an advanced degree. I do not yet know how my party will be made up. Think two or three men will be enough for advantageous work though it is not at all unlikely if I stay long at this quarry that we may have one or two more in order to work extra fast. Do you know of any plug team we can buy? I believe that one horse and a light wagon would do for the men in camp. I may need another team to drive to the little badlands and beyond. I must not fall into the hands of that shark at Crawford this year."

Cook replied on June 30th, warning of the Field Museum party already present in Sioux County, and of Kansas University who were anticipated in a short time. He then informed Barbour of the impending arrival of an American Museum party:

> "The American Museum is also making plans to work here, and I would not be surprised if the Carnegie Museum had something to do with it. There is a relationship between some of the people in them, you know. I would not be surprised if the American came out very soon, as my Grandmother just saw Mr. Peterson and he said so. I will hold myself as a representative of the Uni. [sic] till you come, so as to hold specimens for you."

The idea of a relationship between the American and Carnegie museums probably stems from an awareness of Peterson's earlier employment by Osborn. In fact, as we will see shortly, the appearance of the American Museum at Agate had no connection with Carnegie personnel, but occurred via Osborn's relative, John Adams, who served as liaison between James Cook and Osborn. James Cook encouraged Osborn's entrance at Agate, and this took place in spite of the Carnegie staff's attempt to maintain the hills as their exclusive preserve. However, Barbour fosters Harold Cook's interpretation in his reply of July 2nd to Cook:

> "You are right about it, we ought to be on the ground as soon as possible.... It is too bad that those who have such large sums should skin the state of its best things. You will remember our talks last summer. I am perfectly sure that they will trade the quarry of the Carnegie crowd to the American Museum. I am sorry that it cannot come back to you, in which event the state would eventually secure the splendid material which is going to the eastern colleges. If there is any peddling to be done, your father or yourself ought to be the one considered. It was yours first and it ought to be yours to pass along and not theirs. I haven't a shadow of a doubt that they have agreed to a successor without reference to you or your wishes, but this may not be so. Having been there and having had possession so long, they will naturally come to consider it theirs by right.
>
> "However they are fair men and if they knew that it was

> your wish that it should not be traded to others they would respect your wishes.... Can we bribe you into letting us have some or all your time this summer. We are ready to pay for it. I hope we may be able to accomplish a good deal this season. Next year we must begin to mount some of the skeletons for the new museum. Well, I hope they will not squat on any of the claims which you have staked out for us. We are getting picks sharpened etc., tents ready, and will make a flying start soon."

The flying start was made on July 13th when the Morrill Geological Expedition left Lincoln for Agate. The party in addition to Barbour included E. F. Schramm (in charge), P. R. Butler, and Edwin J. Davis (Fig. 3.13). Fossils found in 1906 by the party were given the suffix 20-7-06. A list of the bones found by each collector was kept in Barbour's field book of 1906-1908 (University of Nebraska State Museum archives), and this list is reproduced in this report as Appendix E. Initially in the field book, an arabic number was appended as a prefix if the specimen was collected by Schramm, a roman numeral if collected by Butler, and a letter if collected by Davis. Later, arabic numbers were assigned as a prefix to all specimens, thus: Schramm, #1-51; Davis, #52-92; Butler, #93-121.

For the first time at University Quarry, a detailed map (Map I) of the bones in the quarry was made. Similarly, in 1908 a companion map was produced. Together, these two maps show the extent of the excavation and the distribution of bones during the Nebraska quarrying of 1906 and 1908, and from this map (Map I), bone orientation and distribution data is taken. The 1906-1908 maps also show the placement of the intact slabs and blocks that were taken from the quarry: these show bone distribution in situ. Only two quarries in the Agate quarry complex were so mapped: University Quarry on University Hill, and the Southwest Excavation (including the earlier Carnegie Quarry 1, and the later chalicothere quarry of the American Museum) on Carnegie Hill.

Two kinds of mammals were common at University Quarry in 1906. Of the 122 bones recorded in the 1906 field diary, 76 belong to rhinoceros (Menoceras), 36 to chalicothere (Moropus), 2 to entelodont (Dinohyus), and 8 are unidentified. These bones represent a minimum number of 4 chalicotheres, 5 rhinos, and one entelodont. Probably only certain bones were recorded in the field diary, primarily the larger or more important elements, since items such as podials and isolated teeth which might be expected to be common are very few.

Bones are scattered and disarticulated. Map I shows very few close associations of skeletal parts. However, the quarry map does indicate a grouping of rhinoceros bones toward the north end of the west bone bed, succeeded to the south by a grouping of chalicothere bones. These groupings appear to be NW to SE trending bands of bone

Fig. 3.13. Camp of the University of Nebraska party in 1906, James Cook ranch, Niobrara River valley, Sioux County, Nebraska.

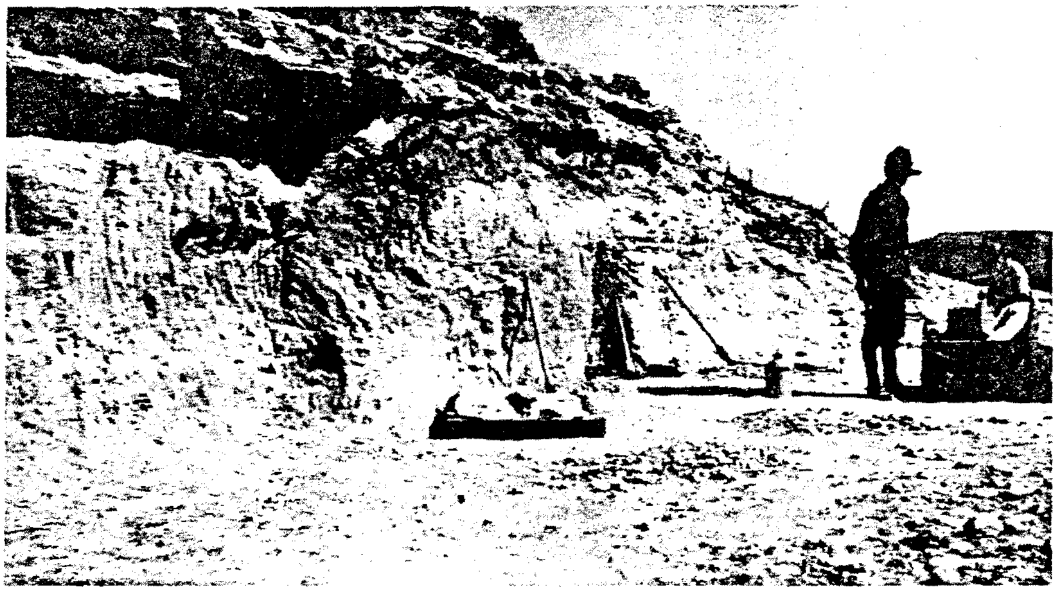


Fig. 3.14. (A) University Quarry, University Hill, in 1906, looking toward the southeast end of the quarry (slab I at center of quarry); (B) University Quarry in 1906, looking toward the northwest end of the quarry, E.F. Schramm in foreground, working out slab II.

(Appendix G), with rhino bones forming a northern band, and chalicothere elements making up a more southerly band.

Dimensions of the 1906 excavation can be determined by restoration of the quarry floor plan, using Barbour's quarry maps. Map I has been compiled from four separate maps found in Barbour's 1906-08 field book. These four maps are accurately assembled using a fifth map from Barbour's field book. The fifth map includes key features that permit the accurate registration of the four detailed maps at a scale of 1/4 inch = 1 foot. By carefully measuring distances between key points on the fifth map, it has been possible to accurately assemble the four detailed maps to achieve a reconstruction of the quarry for the years 1906 and 1908.

The detailed maps in Barbour's 1906 field book show the quarry was divided into sections each 5 feet in length that were marked on the quarry walls. In 1906 the bone-producing zone of the quarry extends from the west edge of section 2 to the west edge of section 12. Thus the actively worked quarry length must have been about 50 feet. Width of the quarry varied from a few feet to about 16 feet (Figs. 3.14A,B).

Two slabs were removed from University Quarry in 1906 (see Map I). Slab I was small, 3 feet 4 inches by 2 feet 9 inches, contained isolated bones, and was sent to Yale University by Barbour. A sketch of the slab (Barbour's field book, 1906, UNSM archives) shows the rear half of a rhino skull, a rhino lower jaw, and three limb bones: these were drawn to orient the block at a later time, and probably all bones on the slab were not shown. I could not locate this slab at Yale in October 1983, and believe that it has been taken apart.

Slab II, measuring about 6 feet by 3 feet, was larger, and survives as one of two slabs from University Quarry still in the possession of the Nebraska State Museum. Bone orientation and density of these two surviving slabs is much like that seen in Slab III collected later in 1908 (and destroyed in a museum fire in March 1912). A photograph of Slab III (Fig. 3.15) published by Barbour (1909) illustrates the orientation and distribution of bones in the quarry. This bone slab demonstrates a moderately dense concentration of isolated bones spread over the surface of the slab, of about equal density in all areas. Density is not as great as the large exhibit slabs at the Carnegie Museum and American Museum removed from Quarry 1 by Peterson and Thomson. Here in Slab III we can see sediment as matrix between bones, with occasional bone-on-bone contacts. The density of bones is about 17 bones/sq. ft. (10 square feet sampled, with a range of 15 to 25 bones/sq. ft.) on the average. Many of these bones are small, or are small fragments of larger bones. The most common elements on the slab are limb bones, podials, isolated teeth, ribs, vertebrae, and numerous bone fragments. One can identify remains of rhinoceros, chalicothere, and entelodont, confirming information reported by Barbour. The density, distribution, and size of bones and bone fragments on the slab suggests, from its position in the quarry (see Map I), that much of the quarry floor probably included numerous fragmented and smaller bones such as podials and isolated teeth. These filled in the areas between the larger and more desired skulls, jaws, and limb bones that were drawn by the Nebraska party on their quarry map (see Map I).

Fossils removed from University Quarry in 1906 are preserved in the collections of the University of Nebraska State Museum in Lincoln.

In 1906, we have the first good sample of photographs of work in one of the Agate quarries: Barbour took 23 photographs, of which 20 survive. Of these 20, 12 show work in University Quarry, one shows Carnegie Quarry 1, two illustrate Carnegie Quarry 2, and 5 show camp scenes. By examination of the photographs of University Quarry under a microscope, the stakes driven into the walls to mark the sections of the quarry can be seen and read. This allows Barbour's maps from his 1906 field book to be placed accurately relative to the modern quarry. On Map A, the westwardly protruding outcrop toward the north end of the quarry, named herein 'Barbour's Point', marks the north end of University Quarry and the position of Barbour's first section stake. This stake can be seen on UNSM No. 8-27-8-06. ('Barbour's Point' is shown in UNSM paleontology photograph Nos. 8-27-8-06 and 5-19-8-06).

<u>North Excavation</u>

The scientific literature on the Agate quarries gives no indication that any work was done on the north face of Carnegie Hill prior to 1907. Previously, there has been no reason to think otherwise. However, during study of the Barbour photographs of 1906 in the University of Nebraska State Museum archives, photograph No. 14-27-8-06 (Fig. 3.16), intended to depict P.R. Butler working in University Quarry, also shows on the distant north slope of Carnegie Hill a small but distinct test excavation in the area where the American Museum quarry of 1907 was to be located. Since this photograph was taken near the end of the 1906 field season, and because the test pit is small, it confirms that no significant digging was done on the north slope of Carnegie Hill prior to 1907. The test pit was probably placed by Utterback or Loomis in 1906, who then went on to other work.

Utterback is the likely excavator, based on (1) Holland and Peterson's (1914, p. 192) statement that Utterback was the first to open an excavation on the north slope (which they erroneously believed to be the east slope; compare Maps A and C in this report); (2) Carnegie Museum No. 1443 - this number, captioned ?<u>Moropus</u> in the Carnegie card catalogue, includes bones collected by Peterson in

Fig. 3.15. Representative slab of bones of Early Miocene rhinoceros, entelodont, and chalicothere found in University Quarry, University Hill in 1908 (Slab III of E.H. Barbour). Bones are scattered and in some cases fragmented, with a density of about 15 to 25 bones/sq.ft. Small isolated compact bones are common, indicating complete disarticulation of strongly ligament-bound parts of the skeleton such as the backbone, foot, wrist and ankle. Such slabs are typical of the attritional bone debris found in this quarry during 1906 and 1908 excavations (see Map I) by the University of Nebraska.

1905. The description reads, "Surface fragments of vertebrae, etc. from the N.E. exposure of the largest hill [Carnegie Hill] in which the quarry is located and which was intended to be opened in the season of 1906 for further investigation." It seems likely that Utterback did open the northeast pocket in 1906.

Included under CM 1443 are numerous bones of Moropus, rare Dinohyus teeth and phalanges, and an uncommon find - the proximal metapodial of a true Diceratherium.

3.1.4. 1907 Excavations

Neither the Carnegie Museum nor the University of Nebraska sent parties to Agate in 1907. The University Quarry and Carnegie quarries lay dormant until the major work of 1908. However, the first significant excavation into the north slope of Carnegie Hill was undertaken in the field season of 1907 by the American Museum of Natural History, New York, under the able direction of Albert 'Bill' Thomson, the American Museum's great field collector of the early 20th century. The year 1907 marks the entrance of the American Museum into the Agate quarries. A series of letters among H.F. Osborn, his relative John Adams, Bill Thomson, and James Cook, describe the sequence of events leading to the beginning of American Museum work at Agate, and illustrate Cook's willingness to have Osborn's men develop a quarry site.

North Excavation

The initial work at this site is closely tied to the first appearance of the American Museum field party, led by Thomson, in the Agate quarries. Field work had not gone well for Thomson and his brother-in-law and fellow paleontologist Paul Miller in June and July 1907. On departing Rapid City, South Dakota, on the first day, Thomson was thrown from the wagon, landing on and both dislocating and breaking bones in his right hand. A month later Thomson wrote Osborn that "I can scarcely use an awl or pick yet and even bothers me to write." In addition, by mid-July, Thomson and Miller were having little luck finding fossils, despite steady prospecting of the 'Lower Rosebud' beds from the area north of Porcupine postoffice to Medicine Root Creek in southwest South Dakota. Miller's queasy stomach and the lack of bones left him depressed.

The opportunity for the American Museum to work at Agate came through a chance meeting of James Cook and H.F. Osborn's relative, John Adams, who was at that time a rancher near Potter, Nebraska. According to Harold Cook, the two men met in Omaha at a livestock association meeting, where Adams mentioned Osborn's interest in the Agate fossils (Cook, 1968, p. 188). This account does not correspond to the tone of letters that passed back and forth between Adams and Cook: these suggest that the letters were the means of the initial approach to Cook by Osborn via Adams. Adams first approached Cook for Osborn on August 22, 1906, while summer field work was still going on in the Agate hills. Cook replied to Adams on September 1st as follows:

> "Your letter of August 22nd received - I know of your relative Prof. H. F. Osborn very well. And I would be glad to have him come to my home at any time and look at the fossil beds about here -" (remainder of this letter appears in section 3.1.3 under E.S. Riggs and the Field Museum).

Adams immediately wrote Osborn on September 7, 1906:

> "Herewith please find enclosed a letter from Mr. Cook in reference to the Agate Quarries. It would seem that Cook is agreeable to a change but that the parties now working there have or seem to have some claims. The accuracy of their assumed rights you will know more about than I do."

By early summer of 1907, Osborn had sent Adams a letter to be forwarded to James Cook, and Cook replied to Adams on June 6, 1907:

> "My dear Adams,
>
> Have read the letter you enclosed written by Prof. Osborn. And I would be pleased to have you write the Professor that it will give me great pleasure to have him come out here and look over our 'old bones'. Dr. Holland of the Carnegie Museum has no one here this spring, and our state university has no funds for the work here in the quarry. All parties that have worked here collecting fossils have done so by my invitation so none of them have prior rights in my estimation. I discovered the quarry and I take great interest in having this great deposit of bones worked out while I am living. My friend, Mr. Peterson, collector for the Carnegie Museum, that has been working here is having trouble with Dr. Holland and is about to quit him I am told. If Prof. Osborn will write me, or better still, come and see me, I will do all in my power to assist him to secure some of the material here.

Adams then extricated himself from these dealings, and asked Osborn to carry on the negotiations in a letter of July 29th:

> "My dear Fairfield,
>
> Replying to yours of July 22 in reference to Mr. Cook's quarry, will say that from the tenor of his letter which I forwarded to you I gathered that he would be pleased to have you work the quarry and was prepared to make any satisfactory arrangements with you to that effect, so I should think it would be more desirable and far more satisfactory to Mr. Cook himself if you took this matter up personally with him. If undertaken by me it would necessitate greater delay, and I am totally uninformed as to what further negotiations would be

desired. In fact I rather think Mr. Cook anticipated your communicating with him after his letter to me."

Osborn sensed opportunity, and probably spurred on by the failure of the 1907 American Museum expedition to the South Dakota Rosebud beds, he wrote Thomson on July 29th:

"Dear Thomson:

I have ... secured an invitation from Mr. James H. Cook of the Agate Stock Farm for us to work in the Agate Spring Quarry, Harrison, Nebraska. I enclose you his letter. I have corresponded with Dr. Holland and Mr. Peterson in the matter and told them that I thought of working in the quarry this season. Peterson gives his approval, but Dr. Holland, as might be expected, speaks of leasing the quarry. They have all the bones they can possibly work up in three or four years and there is no reason why we, having received this invitation, should not accept it. I am writing to Mr. Cook today. I would like to have you write to Mr. Cook telling him you have heard from me and that you hope to be out later in the season - a very courteous letter. Also report to me how long it will take you to move in there in case it proves wise to make a change of base."

The next day (July 30, 1907), Osborn wrote personally to Cook for the first time:

"My dear Sir:

I have just received a letter from my uncle and good friend Mr. John Adams of Potter, enclosing your very kind letter of June 6th inviting me to come out to look over your 'old bone' quarry. I greatly appreciate the invitation and I hope it will be possible for me to come out personally. I have just written to my representative in the field, Mr. Albert Thomson, a first rate fellow, who is accompanied by two or three others, enclosing your letter, and have directed him to write to you.

I informed Dr. Holland of your invitation and Mr. Peterson. Dr. Holland speaks of negotiating for a lease of the quarry from you. I trust that this will not materialize, at least before we have a chance to secure some of your 'old bones' for our museum. The Carnegie Museum and the Nebraska Museum have both taken out larger quantities than they can work up in several years, so that I feel that I am not infringing on anyone's scientific rights in accepting your invitation."

By the 10th of August, Thomson still had little to show for a summer's work, and, discouraged, he wrote to W.D. Matthew at the American Museum:

"My dear Dr. Matthew:

Well Dr. I am sorry to say that we have not met with any success as yet. We found some very promising looking exposures but barren.... Now I am at a loss. I don't know just which way to pull from here. But Agate Spring Quarry is in my mind, and there is only one reason why I don't like to go there. I am afraid Dr. H. would make some unpleasant remark. Though it would be some pleasure to find a few good bones once more.

There is one satisfaction, that is the next party that comes out here to search the Rosebud beds for fossils in the country we have covered this summer will not meet with any success.

Mr. Gregory and Anderson arrived here last evening.... So now we have a good strong party and all we need is fossils.

I am sorry we have not found anything yet. But when the bones are not here we can not get them."

On August 9th, Cook continues to encourage Osborn:

"Dear Dr. Osborn,

Should your Mr. Thomson show up here I will try to do anything I can for him. I have not, and do not expect to lease to Dr. Holland any fossil quarries I may happen to have on my place. There seems to be quite an amount of 'Old Bones' about here. I think my son has found during the past two months several undescribed Beasties. I would be much pleased to entertain you at my ranch home should you care to come and investigate the bone situation here."

On August 13th, Osborn orders the move to Agate, in an attempt to remedy the poor results of the field season in South Dakota:

"Dear Thomson:

I enclose the second letter from Mr. Cook and copy of my reply, which shows that we shall receive the warmest hospitality from him, and he does not recognize any proprietary interests of Dr. Holland; however, this last matter need not be mentioned to him or anyone else.

I have felt all along extremely doubtful about your trip toward the east, but I had relied on Dr. Matthew's judgment which is usually so good. We may at least feel that we have done our duty in exploring those barren valleys, but we have made a very bad start in the way of collections for the season. However, I hope that we shall make a very strong finish through Mr. Cook's cooperation.

The season is so late now that I think it wise for you to move directly to the Agate Stock Farm, making any notes on the way which you think are of importance for future work, but not delaying. Then look the ground over thoroughly with reference to clearing on a large scale, such as that suggested by Dr. Loomis, copy of whose letter was sent to you. My own opinion is that we have a sure thing in this quarry just [as] we had

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Thomson quickly replied to Osborn from Porcupine, South Dakota, on Aug. 17th:

"My dear Professor Osborn,
We are on our way to Agate Spring Quarry and hope to arrive there some time before Sept. 1st.... I am delighted that we have an opportunity to work that quarry, it would be a pity to let that chance slip.... I hope we may be able to make a grand haul at Agate Spring."

More open with Matthew than with Osborn, Thomson writes Matthew on the same day:

"Mr dear Dr. Matthew:
So now we are on our way to Agate Spring Quarry. With the party we have I think that is the best plan as we can surely find something there, besides I hope we may be able to open up that quarry for some good work for next spring. Our museum needs some of that material badly and while we have such a grand opportunity to get it, it seems a pity to not take advantage of it. Dr. H. seems to have queered himself with Mr. Cook."

On August 23rd, Osborn cautions Thomson further:

"I was very glad ... to learn that you are on the journey to the Agate Spring Quarry. You will have to handle the matter diplomatically. Dr. Holland informed me that Mr. Cook intended to reserve for him that portion of the Quarry where the Carnegie Museum had worked. You will have to talk this matter over with Mr. Cook confidentially. Do not mention it to the men, as I especially desire that there should be no gossip about this matter. In short, do whatever Mr. Cook advises you to do."

Thomson reached Agate on August 25th, but refrained from any work at the Agate quarries until James Cook returned to the ranch. On Sunday, September 1st, Cook took Thomson to the main hills and assigned him a work area. A sketch of the quarries in the main hills, drawn in 1907 by Thomson himself, leaves no doubt that the first American Museum quarry was on the north side of Carnegie Hill (Fig. 3.17):

"My dear Dr. Matthew:
We arrived here last Sunday [August 25] afternoon. We did not stop much along the road as we were anxious to get here where the bones grow in bunches.

Mr. Cook was away last week and asked us not to disturb anything at the quarry until his return. So yesterday he went with us down to the quarry and showed us where we can begin our work. Mr. Cook is a very fine man and takes great interest in our work. His son Mr. Harold Cook is a very enthusiastic bone digger and says he will show us some prospects as soon as he has a little spare time. Now I think it no more than right to pay him pretty well for his prospects to give him encouragement to keep an eye open for the A.M.N.H. in the future.

I think it would be a wise plan for both yourself and Prof. Osborn to come out here as soon as possible. That quarry is a great sight and is probably the only one in America. There are bones enough here to supply a great many museums and I do not see why we can not make some arrangement to get that great bone bed divided in some way. Say for the A.M.N.H. to work one half while Carnegie works the other. Mr. Cook is very anxious to see some museum take hold and work out the whole thing, and I think he favors our museum. Dr. H. seems to have queered himself by getting on his 'war horse'. Had I known he would make a muss I would have moved on in the Rosebud taking chances on a failure. But as we are here we shall finish the season, and things may calm down so we can get a chance at the quarry, but our time is so short that we can not do much more than clear space for next year."

And to Osborn on the same day, Thomson provided similar information, but specifically mentioned the location of the first American Museum excavation at the close of his letter:

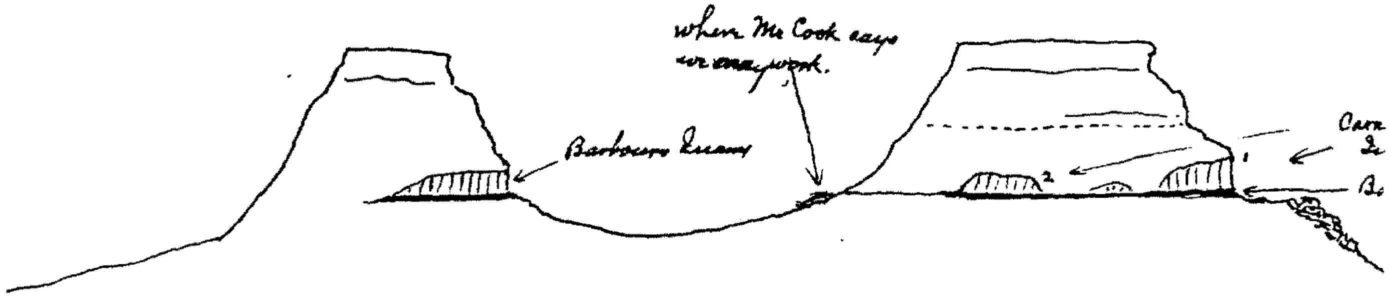
"My dear Prof. Osborn:

We arrived here last Sunday afternoon and had a short talk with Mr. Cook. As he was going away on Monday morning to be absent for a few days he asked us not to disturb anything at the quarry until his return. So yesterday he took us down to the quarry which is I dare say the greatest deposit of fossil bones in America, bones enough to supply many museums.

Mr. Cook is a very fine man and very anxious to have the quarry worked systematically.... Am very sorry to hear that Dr. Holland is up in arms about us coming here. But as cold weather is coming on it is to be hoped that he may cool down sufficiently to come to some reasonable agreement. As there are more bones there than the Carnegie Museum could possibly find room for or work out in the next twenty years.

Mr. Cook has given us permission to work on the north slope of the hill and I hope we have luck enough to open up a good quarry."

Thomson's sketch (Fig. 3.17) of the 1907 American Museum quarry indicates the relationship of the site to the other quarries opened earlier in the main hills. However, the sketch only places the quarry on the north side of Carnegie Hill, without establishing an



The dotted line shows where cut can be made around the hill. About 2
30ft. down to bone layer. Excavating can be done with team and scraper. Pow
can also be used to an advantage. The whole hill can be removed for
I think less than $10,000

Fig. 3.17. Albert Thomson's sketch of the location of the various Agate quarries at the time of arrival of the American Museum party in 1907. University Hill (left) and Carnegie Hill (right) are seen looking southeast. Thomson identified Barbour's Quarry (University Quarry), Carnegie Quarry 1 and 2, and a place on the northeast corner of Carnegie Hill "where Mr. Cook says we may work." This spot became the American Museum Quarry of 1907. Thomson's practical approach to the bone layer is evident in his caption appended to this diagram in his notes: "The dotted line shows where cut can be made around the hill. About 25 or 30 feet down to the bone layer. Excavating can be done with team and scraper. Powder [blasting] can also be used to an advantage. The whole hill can be removed for I think less than $10,000." The plan was never carried out, proving too ambitious an undertaking for the American Museum workers.

Fig. 3.16. University Quarry in 1906 during work by the University of Nebraska field crew. The men use typical hand tools, such as hammer and chisel, awls, brushes, picks, brooms, and shovels to expose and remove the fossils, methods that have changed little today. The photograph, probably taken on August 27th, looks to the south, revealing a small test excavation (see arrow) on the northeast corner of Carnegie Hill that preceded the American Museum Quarry of 1907 in the same location. This test pit was probably dug by either W.H. Utterback of the Carnegie Museum or F.B. Loomis of Amherst College during the 1906 field season.

exact location. Fortunately, Thomson was an excellent photographer. His pictures document much of the work at Agate from 1907 through 1923. Figures 3.18 to 3.21, taken by Thomson, illustrate the exact location of the American Museum Quarry of 1907. The quarry entered the northeast corner of Carnegie Hill (see Map A) at the same place as the small test excavation seen in Barbour's photograph of 1906 (Fig. 3.16). The history of the excavation at the northeast corner of the hill is described in Holland and Peterson (1914), and mentions that both Utterback and Loomis could have been responsible for the preliminary test hole that preceded the larger American Museum quarry:

> "During the spring and early summer of 1907 Mr. W. H. Utterback ... continued the work of excavation which he had carried on in the previous year, and also made an opening on the eastern face [sic - Holland's east face is actually the north face] of Carnegie Hill. Toward the close of the season he left the quarries in order to complete the excavation of one of the Ceratopsia ... in Converse County, Wyoming, and was called home by the death of his father, after which time his connection with the Carnegie Museum terminated.
>
> "After Mr. Utterback had left the spot a party from the American Museum of Natural History entered the excavation made on the eastern side [actually north side] of Carnegie Hill, in which Professor F. B. Loomis of Amherst College had also done some excavating ...."

On Holland's topographic map of the main Agate hills (Map C, this report; Holland and Peterson, 1914, Fig. 1), this quarry is shown by the number 3, and the caption reads, "openings made by F. B. Loomis and subsequently worked by a party from the A.M.N.H."

Thomson's photographs of 1907 prove that the major excavation at the northeast corner of Carnegie Hill was the work of the American Museum. Figures 3.18-3.21 show a distant view of the quarry, and three close views with A. E. Anderson at work. Finally, in Thomson's photograph of the main hills (Fig. 3.18), one has a view that nearly duplicates his own field sketch (Fig. 3.17). The north slope of Carnegie Hill is entirely untouched except for the American Museum site at the northeast corner.

The sequence of excavators at the site remains unclear. Holland's narrative, quoted above, suggests that the initial opening was made by Utterback in 1907, who then was followed by Loomis, with the American Museum party working the site last. We are handicapped in demonstrating this by the failure of Loomis to leave any diaries or records of his 1906-07 work in the main hills at Agate, and by seeming contradictions in Holland's narrative.

First, a test excavation had already occurred at the northeast corner of Carnegie Hill by August 1906, proven by Barbour's photograph (Fig. 3.16). Second, Cook writing to John Adams mentioned that Holland had no one in the Agate quarries in the spring of 1907. Third, the Carnegie Museum Annual Report of 1908 states that Utterback went directly to Wyoming to work on the ceratopsian dinosaur in early spring of 1907, then returned to the east because of his father's death. No mention is made of any work at Agate. Finally, I have not been able to locate fossils or field labels at the Carnegie Museum for any work at Agate in 1907.

Thus, Holland's statement placing Utterback at Agate in spring 1907 is probably an error. We can be certain that the first test excavation was made on the north slope of Carnegie Hill at the northeast corner in the summer of 1906. It was most likely dug by either Loomis or Utterback. I think it most probable that this 1906 pit (Fig. 3.16) was the work of Utterback, then next worked by Loomis in either 1906 or 1907, and finally turned into a large excavation by the American Museum in 1907. Unfortunately, the Amherst College Museum has no fossils or records of Loomis's work definitely attributable to this site.

The only fossils that can be certainly assigned to the northeast excavation of 1906-07 are a few bones in the American Museum, and the group of fossils mentioned earlier under Carnegie Museum No. 1443 (*Moropus*, *Dinohyus*, true *Diceratherium*). Much more must have been found, but these bones probably have been incorporated in the larger Agate collections of various museums without identification of their site of origin on Carnegie Hill.

From Thomson's photographs (Figs. 3.19-3.21), the 1907 American Museum site is not very large (see also Map A). The quarry was probably about 50 feet long and about 15 feet wide. It does not seem to have produced a large number of fossils, nor any fossils of unusual significance. All fossil remains known to date belong to the typical mammals of the Agate quarries in the main hills: chalicothere, entelodont, rhinoceros. A photograph by Thomson (Fig. 3.22) of the 1907 quarry floor is the only evidence of bone distribution at the site. It shows a small pocket of bones, with many individual elements jumbled together, but there is no evidence of a bone pavement like those known from the Southwest Excavation on the opposite side of Carnegie Hill. The pocket seems to be found in a topographic low in the channel, possibly in one of the incised grooves or local channel scours reported in these quarries.

Fig. 3.16. University Quarry in 1906 during work by the University of Nebraska field crew. The men use typical hand tools, such as hammer and chisel, awls, brushes, picks, brooms, and shovels to expose and remove the fossils, methods that have changed little today. The photograph, probably taken on August 27th, looks to the south, revealing a small test excavation (see arrow) on the northeast corner of Carnegie Hill that preceded the American Museum Quarry of 1907 in the same location. This test pit was probably dug by either W.H. Utterback of the Carnegie Museum or F.B. Loomis of Amherst College during the 1906 field season.

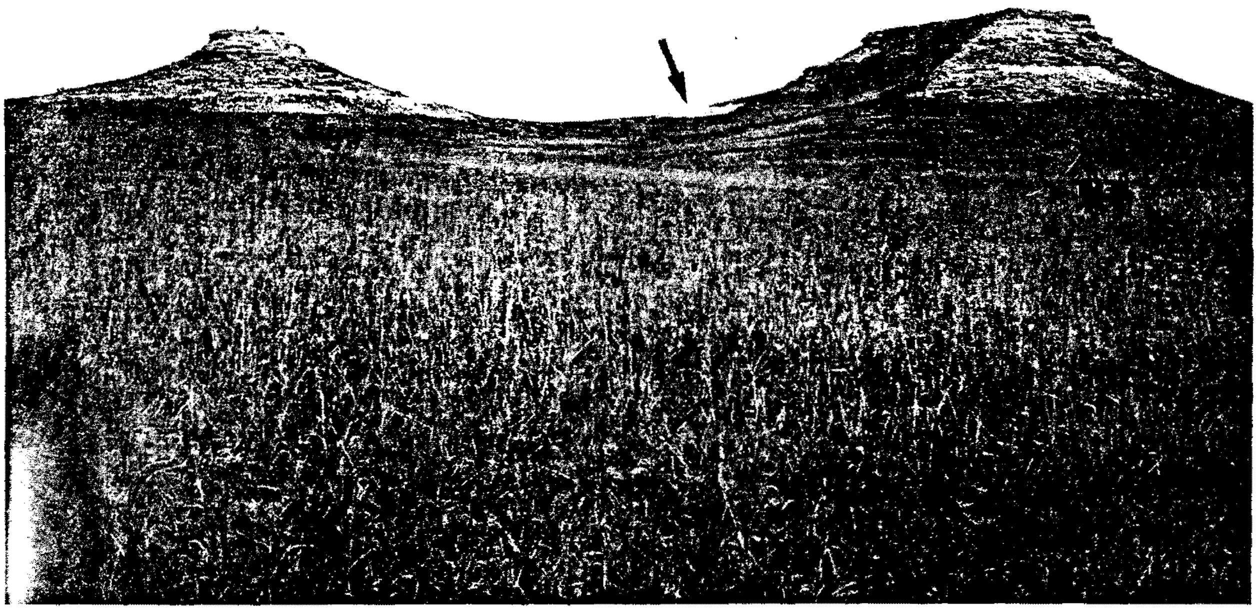


Fig. 3.18. The American Museum Quarry of 1907 (at arrow), shown on the north slope of Carnegie Hill (view looking southeast), was the first site in the Agate hills dug by the American Museum, New York. Work was under the direction of Albert Thomson; only a small quarry was opened since work was begun late in the field season of 1907. University Hill (on left) with University Quarry, and Carnegie Hill (on right) with Carnegie Quarry 2, are the two main Agate hills in which quarrying was carried on from 1905 through 1923 by various institutions.

Fig. 3.19. The American Museum Quarry of 1907, looking south, at the northeast corner of Carnegie Hill. This quarry was placed at the same location as the test pit dug in 1906 in Figure 3.16.

Fig. 3.20. American Museum Quarry of 1907, looking southeast (photograph taken in 1907 by Albert Thomson).

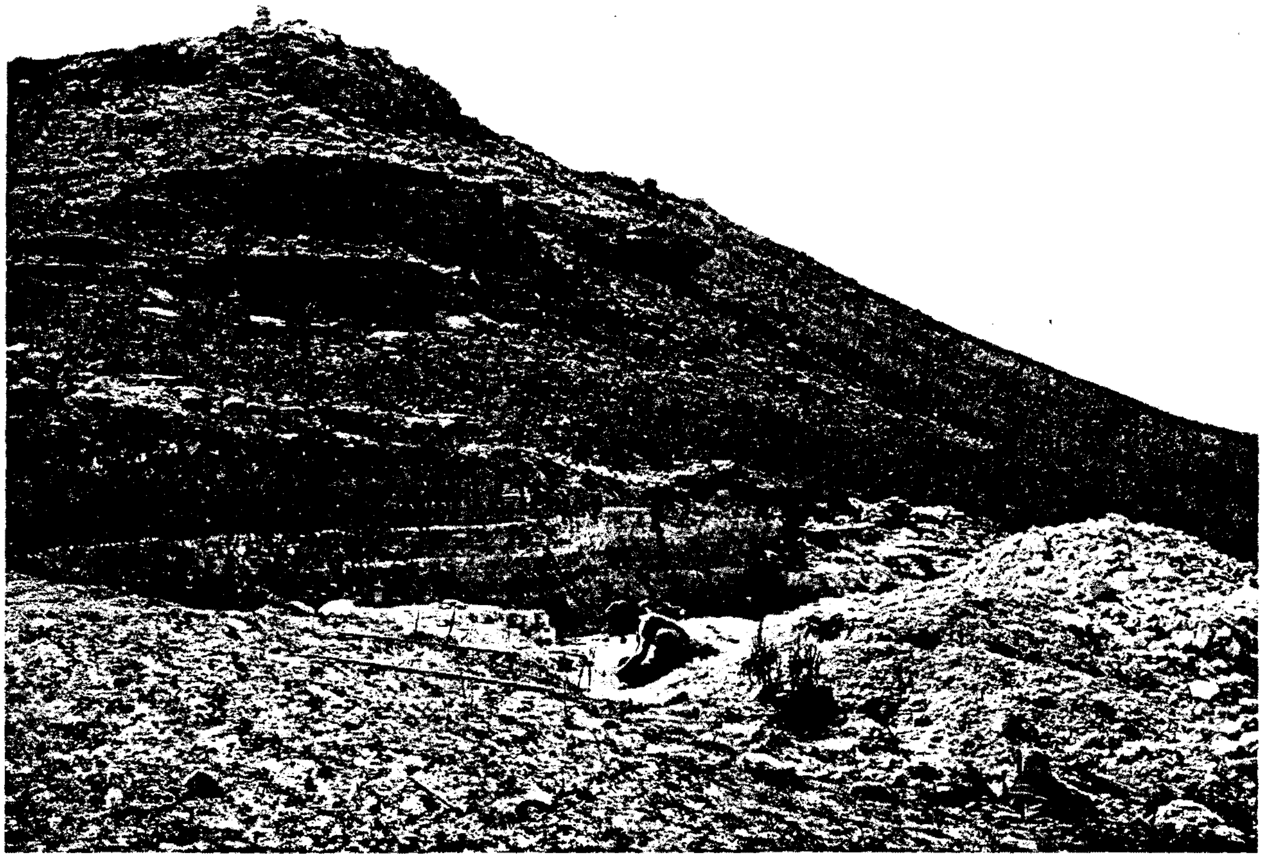


Fig. 3.21. American Museum Quarry of 1907, looking southwest (photograph taken in 1907 by Albert Thomson), A.E. Anderson at work.

Fig. 3.22. Small pocket of disarticulated mammal bones found in the American Museum Quarry of 1907 at the northeast corner of Carnegie Hill. This is the only known photograph of the quarry bone bed in 1907. If this photograph by Thomson is representative, the bone bed here apparently is not as thick and densely packed as in parts of the Southwest Excavation on the opposite side of the hill. Bones appear to be absent from the quarry floor around the pocket, and the pocket itself seems to be a topographically low area within the quarry. The hand awl, hammer, chisels, and brushes are the common hand tools used in excavation of the bones.

3.1.5. 1908 Excavations

Early scientific interest in Agate climaxed with the field season of 1908. Not only did the Carnegie Museum and University of Nebraska return, but Amherst College and Yale University also became involved. In the field during the actual work of collecting, relations between the parties were generally cordial, but behind the scene, the pace of intrigue was brisk. H. F. Osborn held the American Museum out of the quarries in the main hills, yet remained a strong competitor through careful cultivation of the Cook family. Tensions between Osborn and Holland of Carnegie built during this time, accentuated by the discovery in 1908 that the Cooks in fact did not own the land on which the main hills were situated. Holland considered an attempt to lease or lay claim to the hills, but gave up in the end, allowing Harold Cook to file on the land. So discouraging was the disagreement among these parties that the Carnegie Museum withdrew from the main hills after the season of 1908, giving up their quarries (Carnegie Quarries 1 and 2) on Carnegie Hill.

The withdrawal of the Carnegie Museum from the main hills opened the way for Osborn and Thomson to implement their plan to open the main quarry now abandoned by the Carnegie Museum. Under Thomson's leadership, the American Museum began a prolonged program of quarrying on Carnegie Hill that yielded the great chalicothere sample from the Southwest Excavation. But a bonus was also to accrue to the American Museum field men by chance alone; in 1908, during the time the American Museum did not work in the main hills, W. D. Matthew and Harold Cook explored the country about 20 miles south of Agate on the high divide between the Niobrara and North Platte rivers. There they discovered the famed Sheep Creek and Snake Creek beds, rich in fossil mammals of the later Miocene. The Agate quarries and the Sheep Creek-Snake Creek beds formed the focus of American Museum work from 1908 to the late 1920s. A strong relationship between the Cook family and the museum developed, and persisted for many years. In 1910, Harold Cook married Eleanor Barbour, the daughter of E. H. Barbour of Nebraska, and from that time, the Cook family carried on their interest in fossils through interaction with the University of Nebraska State Museum and the American Museum personnel.

Strong prior interest in the 1908 field season was already evident in the fall of 1907 when both Osborn and Holland made personal visits to Agate to discuss work with the Cook family. The flavor of this period emerges from letters of James Cook to Osborn. In September 1907 Osborn made his first visit to Agate. It was undoubtedly cordial, although the details of their working agreement on the quarries are not set down in these letters. Holland came to Agate after Osborn, and in a letter of November 4, 1907, James Cook relates the event to Osborn:

"A short time after you left here Dr. Holland of

Pittsburgh, Pa. arrived at Agate. He remained with us for a few days and I went over the bone hill situation pretty thoroughly with him. I told him it would give me great pleasure if you and he could get together and make arrangements for securing the material in the 'Bone Hill' upon which you have both had parties at work. You will no doubt hear from him if you have not already done so, in regard to the matter."

On the same day, Cook also wrote Thomson with more detail on Holland's visit:

"Since you left we have had the honor of entertaining at Agate Dr W. J. Holland .... He was here for several days and was greatly interested in the quarry his collectors had opened at the bone hills. I went over the whole situation with him, and told him it would give me great pleasure if he and Dr. Osborn could get together and work in harmony in securing the material that I happened to discover at the bone hill. Of course he was not prepared for such a suggestion, and I could see that he was somewhat shocked when he discovered that work had been done upon the opposite side of the hill [the American Museum Quarry of 1907 on the northeast corner of Carnegie Hill]. However he said that he thought that he and Dr. Osborn would be able to make arrangements so there would be no conflict. I am most anxious that this can be done, for I found out while Dr. Holland was here that at heart he is a totally different man than what I supposed him to be. He came 'right down to earth' in his visit to us, and we all as a family enjoyed his stay ...."

Osborn, in his reply to Cook, naturally agreed that he would prefer some friendly resolution of the problem as well. Clearly, this was an inopportune time for the matter of ownership of the Agate quarries to arise, but during Osborn's and Holland's visits, Cook must have brought up this issue, indicated in a later letter to Osborn of December 9th:

"The books you so kindly sent to my son Harold and myself arrived while I was away on a trip to Omaha and Lincoln, hence the delay in my not writing you sooner and thanking you for your most generous gift .... While in Lincoln I met Dr. Barbour and his friend Mr. Morrill, the gentleman that has furnished the funds for Dr. Barbour and his assistants that has enabled them to do a little bone hunting for the Nebraska University during the past few years. These gentlemen both stated that they expected to continue work on the quarry they have opened at the bone hills. I told them that I would be delighted to see them, as well as yourself and Dr. Holland, push the work of securing the material contained in those hills. I also told them what I told you and Dr. Holland as to the chance of those hills being outside of the lands that I actually own and that I thought inasmuch as the lands about here are rapidly being filed upon that something should be done at once in the way of an accurate survey. And if found to be on public domain, measures taken to secure title to the bone hills, placing script upon them if necessary. Mr. Morrill at once suggested that he bring an engineer from Lincoln and make the survey and secure the land, but I told him that I wanted the three institutions now interested in the hills to secure the title to them if a title is needed. I shall write to Dr. Holland today telling him what I have just written you, and I hope that you and Dr. Holland and Dr. Barbour can get together in the work of securing those hills for yourselves. In case you should secure title to the hills, and saw fit to allow me to use the grass upon them and sometimes take a peep at the work in the quarries, I would be content."

Aware of the probable difficulty of working with Holland in such an arrangement, but confident that he could interact with Barbour, Osborn wrote Cook on December 14th suggesting that Nebraska be allowed to purchase the quarry land:

"I am greatly interested in what you say regarding the ownership of land on the quarry. I think it is most appropriate and desirable, if it proves by survey that the quarry is not within your lines, that the University of Nebraska people arrange to take up the land. They belong to the State, they are resident, and both Mr. Morrill and Professor Barbour would, I am sure, take a liberal view of the prosecution of scientific work there. A triple ownership does not seem to me practicable or necessary. I will write to Professor Barbour immediately."

However, by early spring of 1908, it was clear such a plan was unacceptable to Holland at the Carnegie Museum. His irritation at having to share the Agate hills with other competing institutions by now was evident, to him a situation brought on by Harold Cook's solicitation of Barbour, and James Cook's enthusiastic welcome of Osborn's approach through John Adams. In point of fact, neither Peterson nor Holland steadily cultivated the Cooks as did Barbour and Osborn, and as a consequence, the rapport between them foundered through neglect. At the same time, the relationship between Holland and Peterson grew worse, strained since J. B. Hatcher's death in 1904. James Cook described Holland's attitude to Osborn on March 31, 1908; by now, Holland had openly expressed his dissatisfaction with the situation at Agate, and Cook had moved to take the matter into his own hands:

"My dear Dr. Osborn:

I have run against a snag and I write to let you know that Dr. Holland has written me that if other institutions are to be allowed to work at the bone hills he will quit the field at a great loss. He was anxious to buy or lease the quarry so that he might exclude all others from working there, but I do not wish to either lease or sell to him. I tried very hard last year to have all of the three institutions that have worked on the two bone hills to work together in harmony in the interest of science in this locality as the amount of material and the labor required to secure it is so great. It now seems as though my efforts along the lines of harmony have been a failure, and I do not know what is the right thing to do. As I told you when you visited the quarry, I was not sure of my lines taking in bone hills. And I tried to get those interested in working there to help me make an accurate survey, and if the hills were found to be outside my holdings, to take steps at once to secure them by script. No action being taken and all of the vacant lands about here being rapidly filed upon by homesteaders [the Kinkaid Act of 1904 had made homesteading of western Nebraska a popular option], I had a survey made and now I am sure that no one will secure those bone hills that I would not want there. Dr. Holland sails for Germany on the 7th of April. Would you care to interview him before he leaves relative to your working together here? I received a letter from Mr. Thomson recently relative to having some stripping done on the place you worked last season but I could not answer his questions until I know to a certainty that it is now my misfortune to be compelled to choose between those it has been my privilege to meet and have a kindly feeling for among the men of science that are now carrying on the work. My great interest in having the quarry that I had the good fortune to discover thoroughly explored during my lifetime has I fear gotten me into trouble."

Osborn replied to Cook on April 8, 1908:

"Your letter of March 31st was very timely since it reached me just before Dr. Holland's departure for Germany. I spent an evening with him talking over the matter. I find that the interest which I have shown in the quarry has served to revive his interest so that he now desires to work this season at least, on a large scale, and I believe has already sent out Mr. Utterback to begin the work. I will commit to Dr. Matthew who is going out a full statement of the conversation which I had with Dr. Holland as I do not like to put it in writing. I came to the conclusion that it would be wiser since he is actively renewing work for us not to attempt to work this year on the same hill. As you know there are all kinds of people in this world, some who are easy to deal with and some who are not.... The plan I now propose if agreeable to you is this: to have Dr. Matthew and Mr. Thomson go out and form a party with Harold, to do general prospecting in the region."

The result of Osborn's plan turned out well for the museum: Matthew and Cook discovered the Sheep Creek-Snake Creek beds that summer, and opened in them a productive group of localities that today continue to produce numerous later Miocene fossils. In addition, the American Museum group opened a new quarry which Harold Cook had discovered in the fall of 1907. This site, now called the American Museum-Cook Quarry (Hunt, 1972), lies outside the national monument boundaries and produced in 1908 a mammal fauna (chalicothere, rhinoceros, horse, amphicyonid carnivore) apparently equivalent to the Agate fauna of the main hills. By working in the region and by sustaining relations with the Cook family, Osborn and Matthew succeeded in maintaining a presence in Sioux County, wisely waiting for Holland to relax his grip on the site at Carnegie Hill.

Despite Holland's intentions, the field season did not begin well for the Carnegie Museum. Holland sent Utterback to Harrison, Nebraska, to make preparations for the work at Agate in the spring of 1908. After reaching Harrison, Utterback decided to quit the museum, and, during the latter half of April 1908, described his reasons in a colorful series of letters to Douglas Stewart, the museum's assistant director:

> "My dear Mr. Stewart,
>
> Having disposed of our entire outfit the past season it was necessary to replace them this year. Had everything in readiness to leave for the quarry today, when I received the enclosed letter from Mr. Cook [no copy of Cook's letter survives] .... As he has gone to Lincoln and will not return for some time, I do not feel at liberty to camp upon his place until I have seen him. If Mr. Peterson contemplates coming to Neb perhaps it might be well to delay starting until this matter is settled. Should Cook place such restrictions upon us that we cannot work the quarry, then Peterson could take the outfit we have. Horses are very expensive and to get up another outfit will cost considerable."

> "My dear Utterback:
>
> From the correspondence between Mr. Cook and Dr. Holland it seems there was a perfect understanding about the continuance of work in this quarry without any interference from outside parties. I think that Mr. Cook's note to you was simply a desire to talk things over with you before you started work, and do not think he realized he was delaying the work by requesting this. If I were you I would treat it in this manner, and would start work upon the quarry as soon as possible.
>
> Peterson does not expect to start out west until some time later than this, probably not until July. I think you had better go ahead with your work and simply take it for granted that Mr. Cook is going to stick to his first understanding with us. Should any objection be made by Mr. Cook, telegraph me, and we will make further arrangements. In

the meantime, push on the work as if nothing had happened."

Utterback sent a brief note on April 17th, resigning from the museum, and on April 20th explained his action to Stewart:

> "I have decided to give up the fossil business for all time .... In reply to yours of 16th inst will say that I had fully decided not to commence work upon Agate quarry when I last wrote you. Perhaps in the future when Dr. Holland gets a collector to work as hard and faithful in the interests of the Museum as I have endeavored to do, he will not allow any one person to use him for his own personal glorification.
>
> After helping Mr. Peterson out upon this quarry in 1905 when the season was almost closed, with nothing to show for his summer's work, they planned to have me go back with Peterson in 1906 and do all the hard labor while he acted the role of gentleman. It was only when I threatened to throw up my position that they agreed to allow me to work the quarry alone and unmolested. Material that I worked so hard to collect and work out in the laboratory has been put away while other material more recently worked out has been mounted and put upon exhibition.
>
> No, Mr. Stewart, Peterson has preached, written, and boasted of Agate quarry to Dr. Holland until he persuaded him to send old Bill out to do the hard dirty work, and he to follow a couple of months later. Dr. Holland has not kept his word or promises with me since the death of Mr. Hatcher, and I have lost all respect for him. He promised me most faithfully to allow me to continue work upon dinosaurs, both in the field and laboratory, and we know how well he has kept his word. Again the life of a collector is hell, without being subject to restrictions from such bombastic windbags as J. H. Cook. When I have to get down and 'toady' to each and every whim of such damn fools as he, it is time to step down and out. Mr. Stewart, I sincerely regret that this should occur under your administration, as I should be more than pleased to give Dr. Holland just a few parting words...."

And so Utterback departed from the Agate scene. From today's point of view, the lack of any field notes, or maps of his effort of 1906, remains an unfortunate consequence of his assignment to a task in which he had no strong interest. Peterson was immediately detailed to go to Agate to supervise the 1908 field work. This was to be the major season of field excavation; one has to respect Peterson's abilities when, in retrospect, we see what he accomplished. Peterson entered the field without opportunity for thorough preparation in May 1908, and from the start, had to surmount unexpected problems. However, as this report later indicates, this field season eventually proved to be the most successful for the Carnegie Museum at Agate. The largest collection of fossils of any prior field season was secured by Peterson in 1908. In the latter part of May, Peterson wrote Stewart at the museum of his difficulties:

> "Since writing you [on May 12th] I have discovered that Utterback bought a balky team which is absolutely useless for our purposes and must be gotten rid of in some manner .... I find that horses are very expensive in this part of the country on account of the great influx of new settlers. $300.00 is a common price for a fairly good team.
>
> I thought I had all the arrangements completed with Mr. Cook as we both went over the ground together which was my first move after I arrived here. Now I find that after buying the posts for the horse pasture, and part of the lumber for a shanty which I expected to build in order to be more conveniently situated to our work, I had to abandon both since Mr. Cook apparently changed his mind in the designation of the ground for the pasture, which I regard as inadequate as there will not, in my judgement, be feed enough for our stock during the summer and consequently a useless expense. I also now find that he wants me to build the shanty on our 40 of the section of land recently taken by his friend which would necessitate the carrying of water a long distance from the river or digging a well. I got disgusted as I am not in the line of making improvements on other peoples' claims. I have made satisfactory arrangements with a party (Mr. Harris) and am now camped comfortably [at the T4 Ranch] ... about a mile and a quarter from the quarry. I told Mr. Cook that this move on my part is only temporary as Dr. Holland and himself can take up the matter of greater expenditures in connection with this quarry when he returns from Europe. This seems to satisfy him and I will be in shape to start operations in the quarry on next Monday.
>
> I begin to get quite out of patience and wish Dr. Holland was here to carry out his great plans which he and Cook apparently discussed.... Will do the best I can for the interests of the museum."

Carnegie Quarry 1

By June 1st, Peterson's men had reopened Quarry 1 (Figs. 3.23, 3.24). By the end of the 1908 field season, the quarry reached 120 feet in length, 15-25 feet in width (Figs. 3.25-3.27). The quarry was extended in both directions (see Map D), as described by Peterson to Stewart:

> "We have started cuts on both sides of the old quarry No. 1, where the best material was obtained, and are plugging away the best we can with the present force. I am in hopes we may be able to get down to the bone-stratum in a week or ten days. If we find bones as abundant as in the old cut we will be quite busy for a time taking out bones, but if the bones are scattered and we are obliged to cut further into the hill in

the old cut, we have a proposition which requires more men and greater expense, or a long job with small result with the present force.... I understand that the Am. Museum outfit are still camping at Cooks and apparently doing nothing, which is quite amusing and quite curious to me."

Peterson's letter to Stewart from the field on June 7, 1908, is his last of which we have a record for the field season. He continues to discuss his problems with Holland:

"I am naturally very sorry that Dr. Holland (if you have the funds to do it with) does not see the importance of getting through with this work here this year. I, somehow, think that we will not work here another season unless greater concessions are given to parties who own the land. Personally I do not care now, if Holland sees fit for me to have one man or more, the result will of course be accordingly. By having two or three men, as has been decided, it is naturally less for me to manage, and really it is more expensive in the end, for the museum. It was the interest of the institution I had in mind when I proposed to get enough help here this year to make a thorough overhauling of these bone hills.

If you care you may tell Dr. Holland that I have opened a section on each side of the old quarry No. 1 and will be in shape to report on what success we have in finding material here in the near future."

Peterson was aware that this might be the last season for the museum in their quarry at Carnegie Hill. His prophetic remark seems to show his sense of the problems that beset Holland in his dealings with Cook. Indeed, the quarrying of 1908 was the last major excavation by the Carnegie Museum in the main hills. Perhaps only another field paleontologist can comprehend Peterson's trials throughout this period from his discovery of the quarries in 1904 to his departure from Quarry 1 in 1908. Continually pressed by Holland since Hatcher's death, capable yet not permitted to run the operation as he saw fit, his frustrations must at times have seemed unbearable. Yet as a measure of the man, in the years to come, he produced the most comprehensive and numerous accounts of the Agate mammals which today are the major reference sources on the quarries and fauna (Peterson, 1906, 1907, 1909, 1910, 1920).

The 1908 work in Quarry 1 was mapped by Peterson, and published in his monograph on the entelodont Dinohyus in 1909. This map (Peterson, 1909, Pl. 54) has been modified for this report, based on information in field labels and box lists, and is the base for Map D which shows the sequence of excavations by Carnegie Museum parties in Quarry 1 from 1904 to 1908. Using these same Carnegie Museum box lists and field labels, it is also possible to assemble a diagram (Map E) showing the principal types of mammals found in various areas of Quarry 1 from 1904 - 1908. Map E has been compiled by first examining the box list of fossils for a given year. The

Fig. 3.23. O.A. Peterson (far left) and his men in 1908 at Carnegie Quarry 1 on Carnegie Hill (photograph by E.H. Barbour). Note section numbers on the quarry wall.

Fig. 3.24. Peterson and his men at work in 1908 in the north half of Carnegie Quarry 1 (Peterson is at far left seated by box).

Fig. 3.25. Comparison of the restricted extent (B) of Carnegie Quarry 1 as photographed in 1907 by Albert Thomson with the enlarged Carnegie Museum excavation of 1908 (A) under Peterson's direction. The quarry was extended to both northwest and southeast in 1908, the final season of excavation by the Carnegie men at Carnegie Hill.

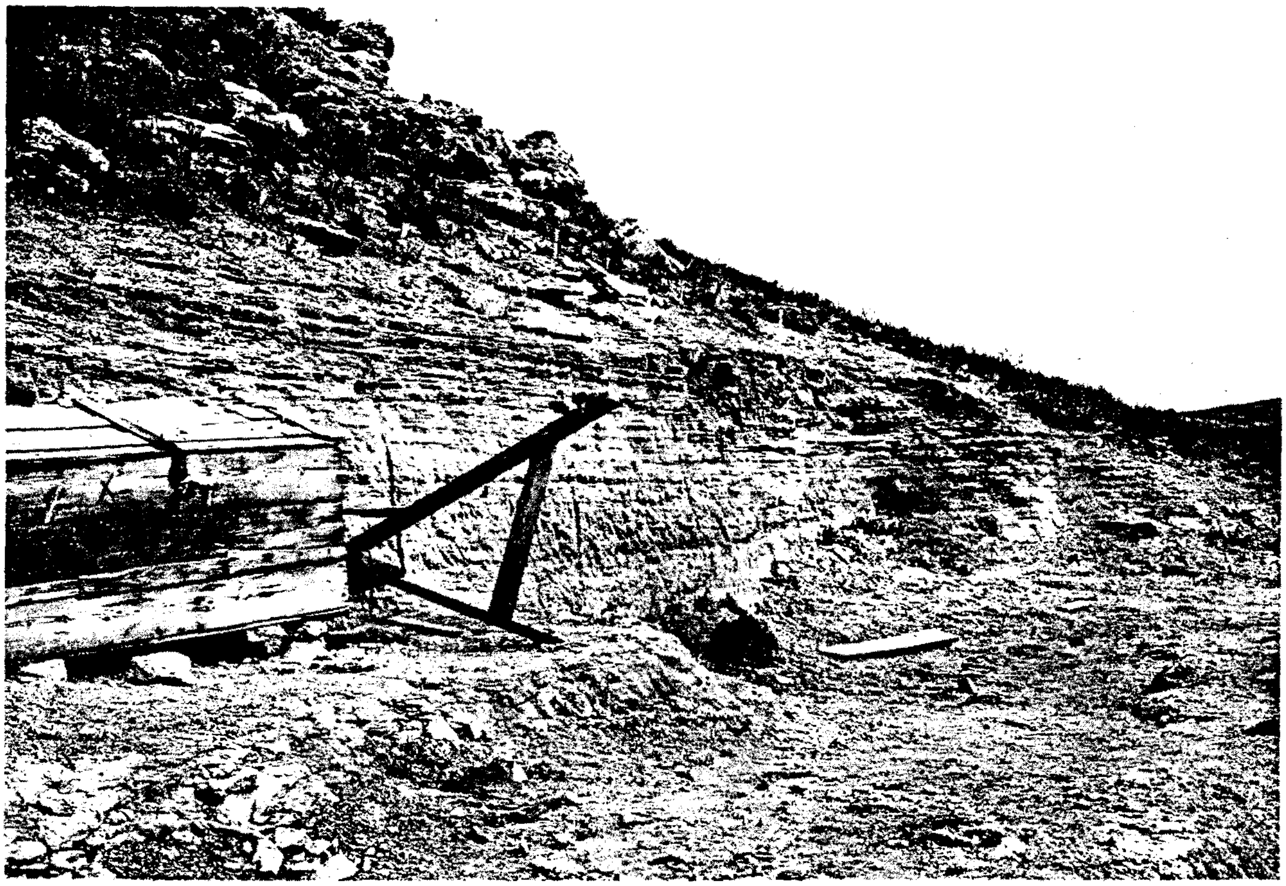


Fig. 3.26. Carnegie Quarry 1 (Southwest Excavation) in 1907 prior to its extension the following year by the Carnegie field party. This photograph by Albert Thomson shows the south end of the quarry that produced a large chalicothere (CM1604) on which Holland and Peterson (1914) based their chalicothere monograph. The large wood box (also in Figs. 3.25B, 3.27) to the left marks the north end of the quarry, still a small excavation in 1907.

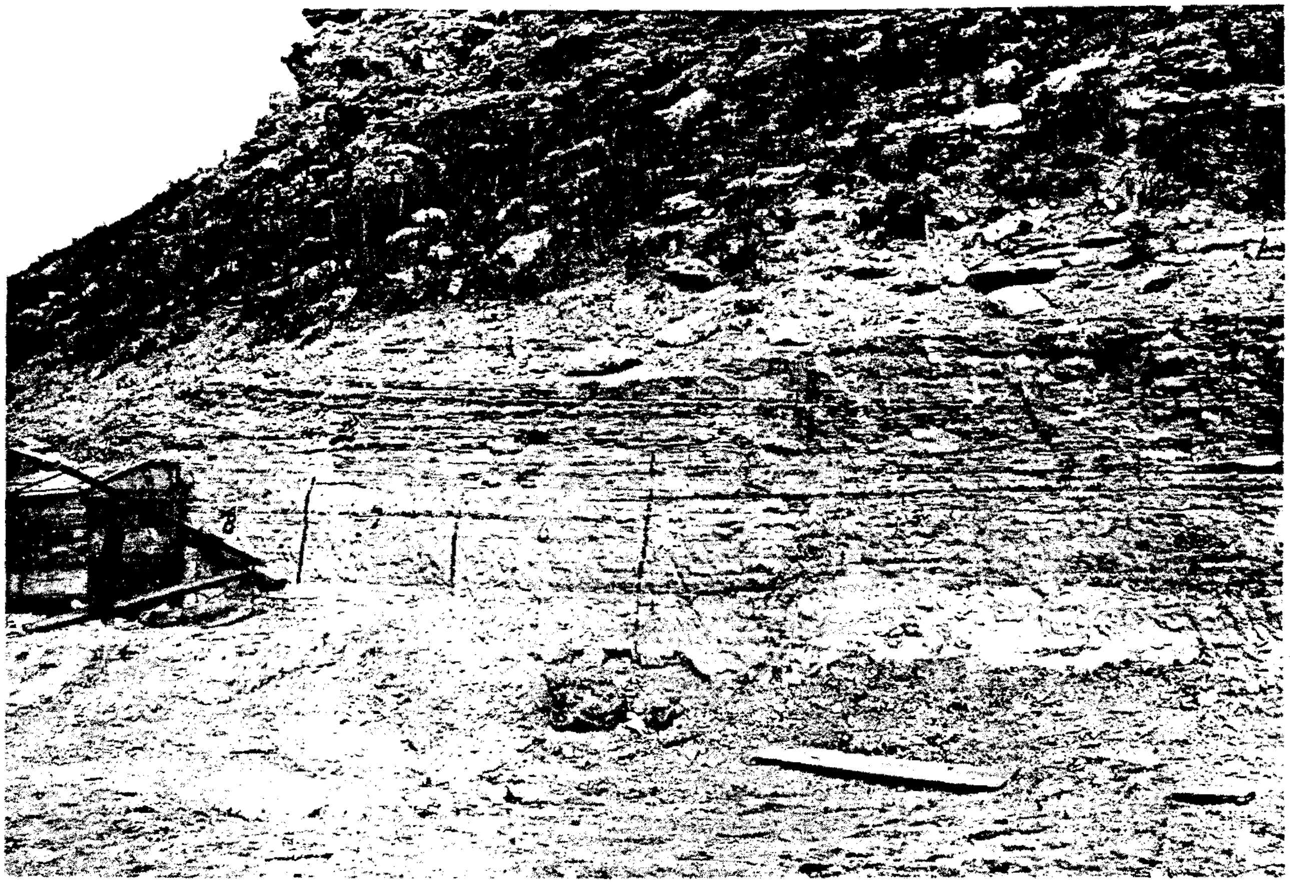


Fig. 3.27. Carnegie Quarry 1 (Southwest Excavation) in 1907 prior to its extension the following year by the Carnegie field party. Section numbers on the quarry wall allow this photograph to be compared with Peterson's quarry maps (see section numbers on Maps D,E in this report). Wood box at left marks the north end of the quarry.

list customarily gives the field block numbers shipped in each box, and also often lists the contents of each block (e.g., Peterson's handwritten notes of 1908 read "Bx. 8 -- Blk. 7 contains Dicerathere [=Menoceras] bones almost exclusively.") Because Peterson mapped the location of Carnegie blocks collected from 1904 to 1908 on his map of 1909, it is possible to accurately locate the contents of many blocks in the quarry. By this method, the mammal content of 81 of 106 blocks could be reasonably determined. From this pattern (Map E), it has been possible to reconstruct the distribution of mammal bones in the quarry.

Three principal kinds of mammals are present in Quarry 1: Menoceras, Dinohyus, Moropus. The central part of the quarry (Map E, Sections 7-16) is almost entirely dominated by blocks containing the rhinoceros Menoceras. Occasional bones of other mammals occur; for example, a rostrum and partial lower jaw of a juvenile Dinohyus (CM 2137, 2137A) are found among rhinoceros bones in Section 12, and other scattered entelodont bones are noted by Peterson, but the bulk of the material is clearly the small rhinoceros. From Sections 14 and 15 comes the large exhibit slab (Block 70), weighing nearly two tons, removed intact to the Carnegie Museum in 1908, which contains almost nothing but Menoceras bones (Peterson, 1923).

Whereas the central part of Quarry 1 contained mostly rhinoceros, the areas to the northwest and southeast of center produced rhinoceros mixed with bones of chalicothere and entelodont. In Map E, the northwest end of the quarry included isolated bones of entelodont and chalicothere scattered among the more abundant rhinoceros elements (Sections 17-21).

Toward the southeast end of the quarry in Sections 1-6, the bones of Menoceras are abundant. In fact, here Peterson reported the discovery of his best rhinoceros skeletal material. But in addition, nearly complete skeletons of a large chalicothere (CM 1604) and an entelodont (CM 1594) were found. The discovery of both skeletons is discussed in Holland and Peterson's (1914) monograph on the chalicotheres of Agate: CM 1604 was almost entirely excavated by Utterback in 1906 but the skull did not turn up until 1908 when Peterson's party located it, completing the skeleton; the large entelodont was the animal unfortunately damaged by Cook's zeal in 1904 while exploring the newly discovered site prior to Peterson's return to Agate.

Most striking about these two skeletons is that (1) they are both partially articulated and almost complete; (2) only one animal of each kind seems to have been present in this part of the quarry (however, rare scattered chalicothere and entelodont bones occur); (3) some bones of each animal seem to have been transported from west to east before final burial. The pelvis and hind limbs of the chalicothere were found in Sections 5-6 where the bones appear to trail off to the east (Map E): both hind legs are directed toward the east, and 1-2 feet directly east of the distal end of these limb bones are scattered foot bones. Ten feet east of these foot bones is the remainder of the skeleton including the skull, jaws, forelimb, ribs, and vertebrae. With regard to the entelodont, some bones appear to have been transported a short distance eastward from the main part of the skeleton.

Throughout Quarry 1, scattered, isolated, and often fragmented bones of other kinds of mammals (equid, camelids, oreodont, large dicerathere rhinoceros, carnivore, bird, turtle) were found (Appendix F), and are indicated on Map E when their location is known. The actual number of these bones is probably greater than indicated in this survey. Such bones might often have been overlooked, especially since they are usually small, broken, and often worn, and many of the field men unexperienced.

It was possible to indicate skulls of _Menoceras_ found in Sections 1 to 10 on Map E, because Peterson often noted the number of skulls in a block, and also mapped a number of skulls in his quarry diagram. Map E does not show all rhino skulls found by Peterson and his men in the quarry, but does provide an idea of their distribution in the southeast half of the quarry where the best data are available. Here the rhinoceros skulls are widely scattered throughout the area, and are not concentrated in one or a few places. In the southeast half of the quarry (Sections 1-9, 1A, 2A), where the most complete count was made, the location of 51 _Menoceras_ skulls can be confirmed. Fifteen additional _Menoceras_ skulls can be located in the quarry's northwestern half (Sections 10-21), where the total count will probably never be known since a number of skulls went unrecorded in this part of the quarry. One then might estimate that about 75 to 100 _Menoceras_ skulls were present in Carnegie Quarry 1 in the excavated area worked from 1904 through 1908. In 1920, Peterson would place the count at about 200.

Carnegie Museum field records also document the occurrence in Quarry 1 of occasional partially articulated skeletons of _Menoceras_. These include a series of vertebrae, a partial limb, lower jaws with a string of vertebrae, a partial foot. Partial articulations are probably more common in the quarry than realized, since the collectors comment that such articulations often are first noticed when a block of fossils is brought to the laboratory and prepared.

The fossils removed from Quarry 1 in 1908 are maintained by the Carnegie Museum, Pittsburgh. Many fossils from the excavation were used as exchange specimens by the museum, going to other academic institutions in North America and Europe. In addition, Peterson's preparation notes show that some blocks were prepared by local schoolchildren and many bones destroyed or lost. At this time, much of the material was regarded as duplicate stock-in-trade, and not as a population sample of an extinct rhinoceros.

Photographs of Carnegie Quarry 1 as it existed during the 1908 field season are few. Peterson left none in the Carnegie Museum archives; a few negatives may show the 1908 work, but lack definite identification, and cannot be certainly attributed to this year. Fortunately, E. H. Barbour photographed both the excavation and Peterson's party (Figs. 3.23, 3.24, 3.25A). The condition of the Carnegie quarry at the start of the 1908 field season can be seen in photographs taken by Bill Thomson in 1907; these show the dormant Carnegie site during the 1907 season prior to the resumption of work in 1908. Thomson's pictures indicate that the quarry in 1907 included only Sections 1 to 9 and was not a large cut (Fig. 3.25B, Maps D, E). Section numbers marked on the quarry walls are legible in the photographs. So we can be certain that the northwestern half of the quarry (Sections 10-21) was first developed in 1908, as were the extreme southeastern sections designated 1A, 2A (up to 4A).

In summarizing the field work of 1908, Peterson wrote in his annual report that "In the beginning of the month of May, I was detailed to take charge of the field expedition which had been sent to the Agate Spring Fossil Quarries .... The work in these quarries was carried on very nearly the entire season. The material secured is for the most part [Menoceras] cooki, although much important material of Dinohyus hollandi and Moropus elatus was also secured in quarry No. 1. Sixty boxes of material were collected from this quarry."

Before returning to Pittsburgh, Peterson excavated briefly in Stenomylus Quarry, discovered in 1907 by Loomis of Amherst College, about 1 3/4 mile east and slightly south of the main Agate hills. During the 1908 field season, Lull of Yale, Loomis of Amherst, and Thomson of the American Museum also worked the site. A dispute arose over Peterson's choice of a work area which, Thomson believed, infringed on the American Museum quarry. Peterson felt that no breach of proper field procedure had taken place. He summarized his 1908 work in the quarry, "The last part of the season a new and interesting quarry was opened in the general neighborhood of the Agate Spring Quarries which yielded very fine material. Eight skeletons, more or less articulated, of a small species of camel were found. Many individuals which were disarticulated were also secured from this quarry and all the material was packed in ten boxes." Peterson would return in 1909 for a final period of work at Stenomylus Quarry, but the major excavations of the Carnegie Museum had come to a close, as Peterson himself had earlier predicted. The star of the American Museum was now in its ascendance. Osborn's tactful planning had fully supplanted Holland's more aggressive attempt to secure Agate for the Carnegie Museum.

University Quarry

Encouraged by the support of the Cook family, Barbour worked his quarry in University Hill in 1908, his last major effort in the main Agate hills (Fig. 3.28). Through financial backing of the

Lincoln banker, Charles Morrill, the party left Lincoln for Marsland, Nebraska, on June 30, 1908. Barbour's men included J. A. Bumstead, Leigh Krake, Edwin Davis, and --- Van Orsdel (Fig. 3.29). The party began work at the quarry in early July, dynamiting the thick rock overburden above the bone layer (Fig. 3.30). Results of the blasting appear in photographs dated July 14, so major excavation does not seem to have begun until mid-July (Fig. 3.31A,B). Work in the quarry continued until the end of August: the closing of the quarry was photographed on August 28-29 (Figs. 3.32, 3.33), and other photographs show the crew at the site as late as September 6. By the second week of September, the party had returned to Lincoln, taking with them four tons of material from the quarry. E. H. Barbour, usually immaculately attired in the formal dress of the day, appears in several rare photographs in field clothes (Fig. 3.34), laboring in the quarry, and field records indicate that many specimens were personally worked out by him.

Dimensions of the 1908 excavation are shown in Map I. In 1908, the University of Nebraska party extended their initial excavation of 1906 into the hill by about 15 feet, with a north to south working length of 50 to 60 feet. The 1908 excavation was offset to the south relative to the 1906 quarry, so that the total north-south length of the two excavations on Map I measures 75 to 80 feet. The initial 1905 excavation by Pepperberg's crew was about 108 feet long, thus the quarry length in 1906-1908 appears to have narrowed in the north-south direction. However, in 1905 Pepperberg apparently measured the length of the quarry parallel to the side of the hill in a northwest-southeast direction. Today the present quarry is almost exactly 108 feet long (Map A) when measured parallel to the face of the hill, suggesting that indeed Pepperberg did take his quarry length along a NW-SE transect (his quarry map does not give an oriented direction). If one measures length of the bone-producing area on Map H for the 1906-1908 excavations along a NW-SE transect approximately parallel to the side of the hill, the quarry length would measure about 80 feet (Figs. 3.35, 3.36).

Bone distribution in the quarry is also shown on Map I, compiled from Barbour's quarry diagrams. Because he mapped many individual bones as well as blocks, it is possible to obtain a reasonably accurate overview of bone distribution. Here for the first time in any of the Agate quarries we can learn something of the channel topography and its relationship to bone distribution and orientation. Bones from both 1906 and 1908 are best considered together. They occur in two linear groups, a principal NW-SE aligned band of bones extending from Section 4 to 12, where it is joined by a smaller N-S aligned band found in Sections 6 to 11. The two bands appear to come together in Section 12 where they join to form a common stream of bone, passing to the southeast between two topographic highs within the channel. My field observations of the quarry indicate that a NW to SE-trending channel is incised into the Harrison Fm. at this point on University Hill. Bones that I have examined in the University of Nebraska collections from this deposit are usually rounded and worn, evidence of fluvial abrasion.

The bones taken from the quarry in 1905 were not uniformly distributed over the excavated surface, but rather were concentrated toward the north end of the site. Pepperberg recorded in his field diary on August 8th that "Steck and Jack run out of bones -- find a few more by stripping through hard stone." In Figure 3.6, Steckelberg and Jack Miller worked the south end of the quarry where we now see from the pattern of bone distribution (Map I) that the margin of the channel should be found. Bones in 1905 should have been concentrated in Sections 1-8 at the north end of the site where the NW-SE trending bone stream emerges from the side of University Hill. This was the area worked by Lee and Pepperberg, and indeed these men found the densest bone concentrations and the deepest bone pockets (Figs. 3.5, 3.6). So the 1905 excavation results are in accord with the bone pattern mapped in 1906 - 1908.

University Quarry tapped an ancient stream channel accumulation of bones buried in fine grained sandstone. The bones show abundant evidence of fluvial abrasion, and gnawing and breakage by predators/scavengers. Bones demonstrate preferred alignments within the channel (Appendix G). These orientations were the result of stream currents of sufficient energy to align some of the larger bones known from the site (e.g., limb elements of chalicotheres). Here in this quarry the fossils cannot be exclusively the product of a catastrophic event, instantaneously preserved in a mass grave of sandstone. The University Quarry bone bed is unequivocally the result of events of longer duration, involving skeletal disarticulation, scavenging, weathering, and transport, which sort and process bones over a period of time (Fig. 3.37).

Just as in the other quarries in the main hills, the small rhinoceros (Menoceras), chalicothere (Moropus), and entelodont (Dinohyus) are the most common mammals found at University Quarry. Map I indicates that the western portion of the quarry excavated in 1906 produced primarily rhinoceros and chalicothere. These bones make up the NW-SE trending bone stream mentioned earlier. A few isolated entelodont bones were found in this part of the quarry, but they are rare. However, the eastern portion of the quarry excavated in 1908 included, in addition to rhinoceros and chalicothere, many bones of entelodont. Some of these entelodont bones are scattered within the N-S trending bone stream of Sections 6-11, but most bones are concentrated in the channel between the two topographic highs at the southeast corner of the quarry (Sections 12-15). Much of this mass of entelodont bone belongs to a single large individual (UNSM 1150, UNSM field #25-20-7-08), today the best preserved skeleton of Dinohyus known (Fig. 3.38). No articulated or semi-articulated mammals were found in the quarry except for the large entelodont. Parts of skeletons occur in which a few bones are in life relationship, indicating ligament and other connective tissue held them together, but these are not common.

Other mammals are as scarce at University Quarry as in the quarries on Carnegie Hill. Rare and often worn bone fragments of equids, camel, and carnivores have been found. Carnivore remains are chiefly isolated bones of beardogs (Amphicyonidae); two of the first bones found at University Hill in 1904 by Peterson when he first explored the hills belonged to the beardogs Daphoenodon and Ysengrinia (Hunt, 1972). Two bones of the hind foot of the primitive digitigrade ursid Cephalogale have also been discovered among fossils collected at University Quarry. These few carnivore fragments occur in University Quarry in about the proportion one would expect if the ratio of carnivore to herbivore bones were to approximate the carnivore/herbivore ratio in modern mammal faunas. These are the fragmentary remains of carnivores that, through normal attritional processes, have worked their way into the University Hill channel.

Six bone slabs were removed from the site in 1906-1908. Slabs I and II were discussed earlier as part of the 1906 work. Slabs III through VI were collected in 1908. The largest of these was Slab III, about 4 by 6.5 feet, which was destroyed in a museum fire on March 6, 1912. Bone density in Slab III ranges from 15 to 25 bones/square foot (see p. 73), averaging about 17 bones/square foot. Figure 3.15 is the only photograph of a slab from University Quarry that has survived; this photograph confirms Barbour's claim that Slab III included the three common Agate mammals. Slab IV measured about 5.25 by 2 feet and contained mostly rhinoceros. Slab V survives only as a sketch in Barbour's 1906-1908 field book where it comprises a mass of intermixed vertebrae, ribs, and a scapula -- on the basis of size and morphology, these appear to be primarily Dinohyus bones belonging to the large skeleton in Sections 12-15. Slab VI also has not survived intact: it included many chalicothere bones, possibly some rhinoceros and entelodont; Barbour indicates that this slab was taken from an area with much Moropus material.

One of the classic tales of Agate turns on the southernmost fossils diagrammed in the quarry in Sections 15-16. A large block labeled 'Slab Y' was removed by Hugh Gibb of Yale and taken to New Haven, where upon being prepared, it was found to contain the femur and tibia of a large entelodont. The remainder of this skeleton (UNSM 1150) had gone to the Nebraska State Museum. The Yale team and the Nebraska men had each inadvertently removed part of the same entelodont while working near each other in University Quarry. In November 1914, the limb and a few other bones were returned to Lincoln, and the skeleton restored.

The collection from University Quarry is particularly important in reconstructing the origin of the Agate bone bed because Barbour mapped the position of many individual bones, numbered them, and indicated their orientation in the deposit. To this mapping, he added the topographic high points within the quarry which help to interpret the pattern of bone distribution. We know that such topography existed in other quarries (North Excavation, Figs. 3.22,

Fig. 3.28. Bone diggers' camp north of the Agate hills and Niobrara River in 1908, located near the present monument headquarters (view looking north). Field parties from Yale, Amherst, the American Museum, and the University of Nebraska were photographed here by Albert Thomson. The University of Nebraska's tents are to the right of Utterback's 1906 wood shack, the Yale tents are immediately in front of the shack, and Amherst's camp is to the left. The 3 tents of the American Museum party are in the left foreground. Hill in center background is easily recognized today as a landmark.

Fig. 3.29. University of Nebraska field crew of 1908: from left to right, front: Davis and Krake; rear: Bumstead and Van Orsdel. Section numbers 8-10 appear on University Quarry wall behind the men.

Fig. 3.30. Blasting in University Quarry in 1908 to remove rock overburden above the bone bed. In all quarries, blasting was preceded by drilling to place dynamite charges which would displace rock but not damage the bone bed. To accomplish this, Agate field crews became highly skilled in drilling technique.

Fig. 3.31. (A) Drilling the rock overburden in University Quarry prior to blasting in 1908, looking north. A 2-horse team and scraper similar to the one shown here were used in all quarries to remove rock after blasting. When the scraper approached the bone bed, the men turned to hand tools to avoid damage to the bones; (B) Rock rubble resulting from blasting in University Quarry in July 1908.

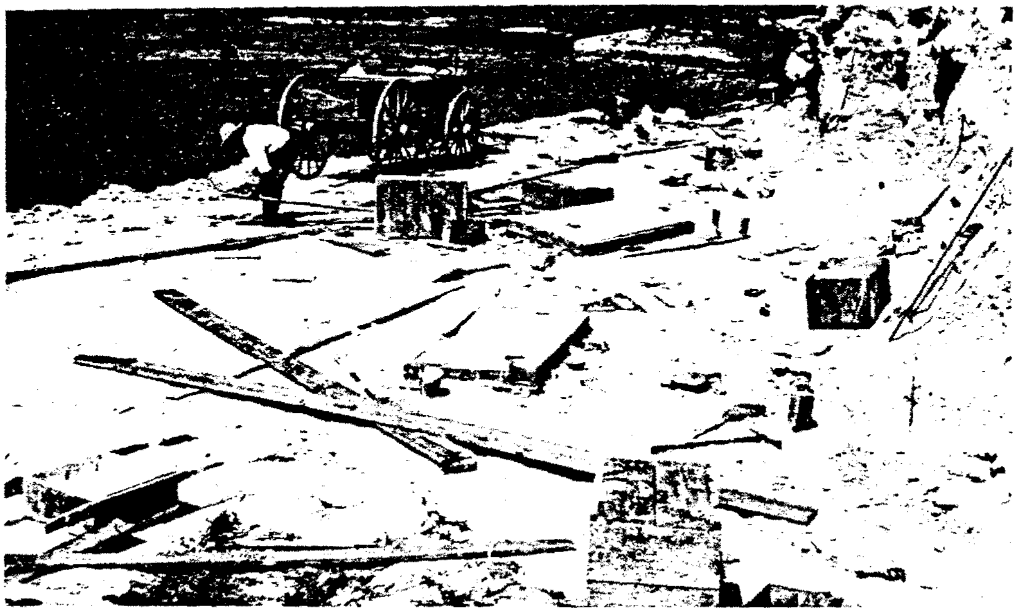


Fig. 3.32. (A) Closing of University Quarry in late August 1908, with North Ridge in middle distance to northwest. Two rectangular bone slabs lie on the quarry floor (center), ready for crating; (B) University Quarry in early September 1908 at end of field season, looking northwest. Bone slabs and crated fossils were transported by team and wagon to the railroad depot at Andrews, Nebraska, for shipment to Lincoln.

Fig. 3.33. West side of University Hill in September 1908, showing the extent of University Quarry at the close of excavation by the University of Nebraska party under Barbour's direction. Today the quarry is nearly identical in its dimensions to the 1908 cut. Bones are found at the base of an incised stream channel which can be seen in cross-section on the west face of the hill. The horse and wagon mark about the deepest point in the channel, the base rising to the south (right).

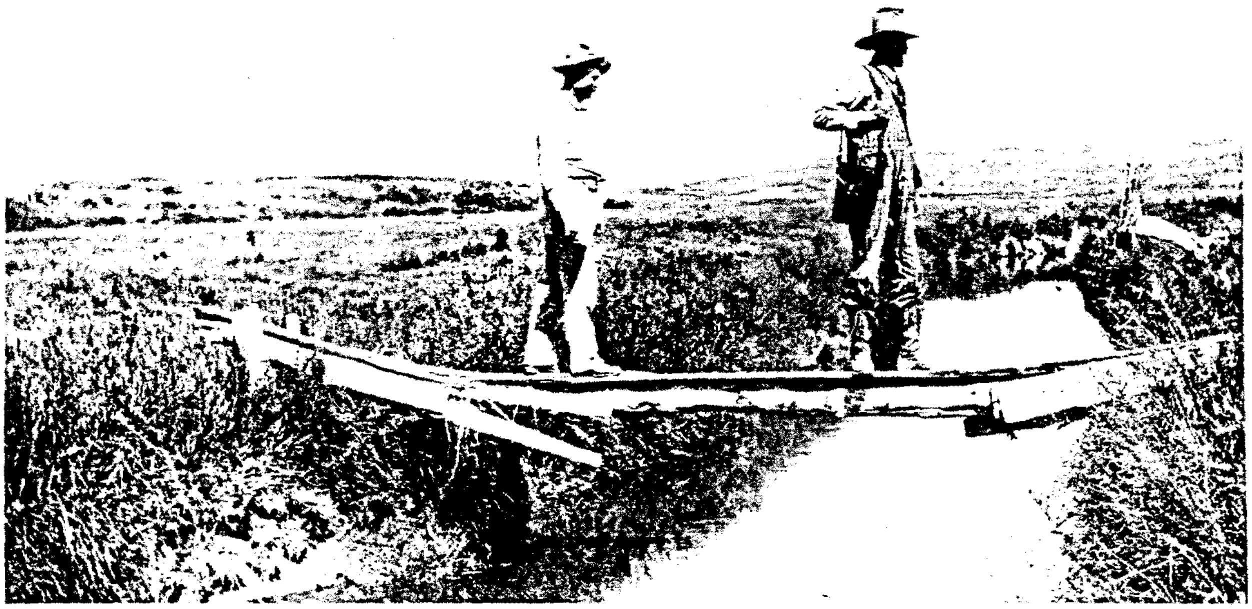


Fig. 3.34. Hugh Gibb (left) and E.H. Barbour (right) crossing the log bridge over the Niobrara River between camp and the quarries in the main hills, on August 24, 1908.

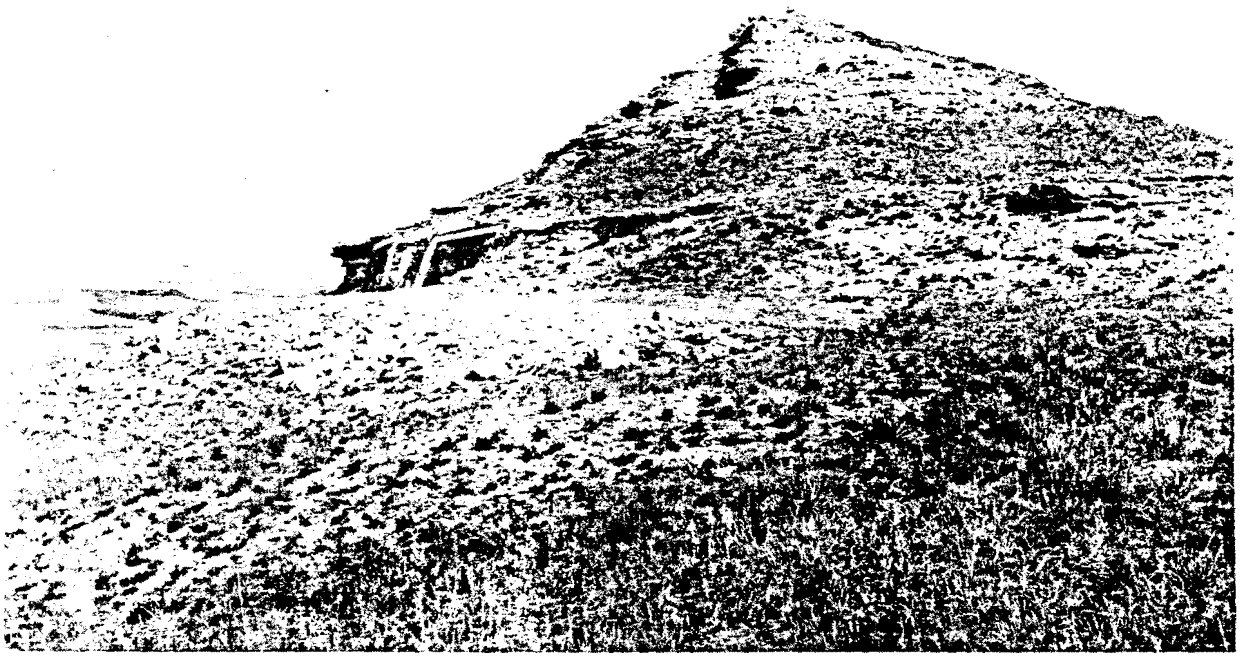


Fig. 3.35. University Quarry from the south during the field work of 1908.

Fig. 3.36. University Quarry under excavation by the University of Nebraska party in August 1908. Scaffold was draped with canvas to protect the men from the sun.

Fig. 3.37. Working floor of University Quarry's south end in August 1908, showing the level of the bone bed, and the area that produced the nearly complete entelodont skeleton (see Map I). Pelvis in foreground, other bones leading to skull (25-V) in background, looking north. The south end of the quarry was worked cooperatively by both Nebraska and Yale parties.

Fig. 3.38. Edwin Davis of the University of Nebraska working on the large block (25-V) containing the skull of the entelodont Dinohyus at the south end of University Quarry in August 1908. On exhibit today at the University of Nebraska State Museum, this specimen (UNSM 1150) is the most complete and best preserved entelodont to come from the Agate quarries.

3.64; Southwest Excavation, American Museum chalicothere quarry, Fig. 3.67) on Carnegie Hill, and so probably is a common feature of the environment of deposition. In his discussion of the origin of the Agate bone bed following the 1908 field season, Peterson (1909, p. 75-76) set down his observations made at University Quarry after the departure of the Nebraska workers. Barbour had mapped the location of topographic highs of reddish sandstone entirely lacking in fossils in plan view in his field notes, but never published this information. Peterson (1909, Fig. 28) did publish his observations of the same topographic highs mapped by Barbour, and presented this as a cross-section running parallel to the long axis of University Quarry (Fig. 3.39).

Peterson's cross-section (Fig. 3.39) establishes the validity of Barbour's map (Map 1), and together the map and figure provide a very good reconstruction of the nature of the quarry floor. The following points can be confirmed: (1) the two topographic highs shown in Sections 11-12 and 14-15 of the quarry; (2) the presence of a major channel margin at the south end of the quarry where the bone layer ends (this prominent channel margin can be observed at University Hill today, where it continues to rise to the south until the southern edge of the hill makes further observation impossible); (3) the concentration of bones densely packed in narrow channels and localized pockets; (4) a maximum topographic relief of about 2-3 feet between the base of the bone-filled channels and the top of adjacent intra-channel highs.

Initially, Peterson (1906) believed that the Agate bone bed formed in a lacustrine depositional environment, but in 1909 he argued for a stream setting for the bone bed, and his reasons fit well with the accumulated data of this study:

> "The origin of the deposit in which the fossil bones of these quarries are found is most likely a stream deposit. In support of this view may be cited the fact that the parting plane underneath the layer carrying the bones is a few shades darker in color than the layer itself, and the bones are often closely packed in irregular channels and pockets, which vary in thickness from two or three to eighteen or twenty inches (8 to 50 cm.). The surfaces of the bones are sometimes highly polished and worn, and there are numerous fragments of bones which are worn down to the shape of a pebble. These conditions could have been brought about in no other way than by the action of water in motion. There was here most likely a stream of considerable magnitude, instead of a lake, as was suggested by the writer [in 1906]. The fossil-bearing bed has all the appearance of a stream the bottom of which was covered by quick-sands. In the quarry located on University Hill ... there are distinct evidences of narrow and rather shallow channels, which were separated by sandbars of greater or lesser dimensions. The bone layer of this quarry is thus irregularly separated, although confined to one general level

throughout portions of the base of the hill."

The observations made by Barbour and Peterson at University Hill clearly define the nature of the surface on which the bones were deposited. A primary stream channel possessed a floor cut by smaller irregular linear subchannels which often filled with bone debris. The bone-filled grooves are independently confirmed by Pepperberg's mapping in the quarry (Fig. 3.6C) in 1905. At Carnegie Hill, photographs of the North Excavation and the Southwest Excavation during work by the American Museum in 1907 and 1920, respectively, also suggest such linear grooves filled with mammal bone. But it seems surprising that Peterson or Thomson did not map or better describe such features in the quarries on Carnegie Hill.

Fossils from University Quarry are maintained in the collections of the University Of Nebraska State Museum, Lincoln. Archives of the museum contain the field notebooks of E. H. Barbour (1906-1908) and L. J. Pepperberg (1905) which record the details of the excavations.

Yale University Excavation

In 1908, R. S. Lull, Professor of Geology at Yale, and his head preparator, Hugh Gibb, journeyed to Agate to take part in the work at the Agate hills (Fig. 3.40). They left New Haven on June 12th to join F. B. Loomis and his party at Amherst, leaving Amherst the same day by train on the trip west. On June 14th, they reached Lincoln and were met by Barbour who escorted the party through the State Museum, with its Agate collection. Lull in his journal remarks on the small protoceratid antelope *Syndyoceras* and Barbour's skull of *Moropus* from University Quarry. About 11 PM Loomis and Lull left Lincoln by train for western Nebraska, reaching the town of Crawford the next morning. Lull recorded his initial meeting with the Cooks on June 15th in Crawford:

> "Awoke in the western part of Nebraska on the high plains, very few trees and fine cattle. Should have reached Crawford about 8:30 AM but at Alliance one of the express cars ran two wheels of the forward truck off the track cracking a wheel and necessitating the removal of the car which delayed us all the more. Arrived in Crawford. Went to the Gate City Hotel, a pretty poor place but the best in town. After dinner we ... met Mr. Cook and Harold of the Agate Spring ranch. Loomis and I had a long talk with Mr. Cook after supper. He showed us the difficulties in the way of our coming to Agate Spring Barbour quarry but we hope it may be smoothed over."

The next day Lull traveled to Lusk, Wyoming, with the Amherst men and Harold Cook, Lull developing an immediate liking for the 20 year old rancher. On June 17th, operating as a joint Yale-Amherst party (Figs. 3.41, 3.42), Loomis and Lull purchased an outfit from a

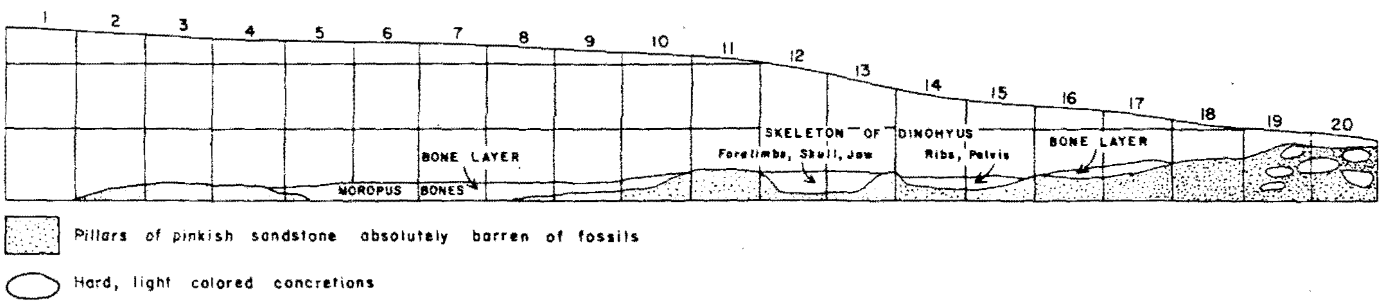


Fig. 3.39. O.A. Peterson's north-south cross-section of University Quarry in 1908, showing the irregular topography of the quarry floor; bones fill the low areas. Note the channel margin rising to the south, observable today on the west side of University Hill. Compare this cross-section with plan view of Map I.

ranch near town, and on their return to Lusk to shoe the horses, Lull wrote: "They brought in a murdered man who had just been found about two miles out -- had been shot in the head. A lurid town." Leaving town the same day, the party traveled south from ranch to ranch, finally making their permanent camp at Muddy Creek in the Hartville Uplift. For about one month (June 19-July 13), the Yale-Amherst party collected fossils from the Arikaree rocks of the Hartville Uplift and the tableland to the east in Goshen and Niobrara counties in Wyoming. On July 13th, Lull records the journey to Agate in his field journal:

> "We rose at five, broke camp and pulled out at 7:15 AM on the long trail to Agate.... we progressed along the valley of the Rawhide creek until we arrived at the Crawford [not the Nebraska town] ranch at noon, a distance of some 15 miles. From there we drove due east across the rolling prairie covered with the finest cattle 010 brand, some 8000 of which belong to Crawford. We were to make Bush's ranch but the way was very long and about six we arrived at a dismantled windmill where we camped. We had no drinking water but there was a muddy pond for the stock. I fired two shots at a great gray wolf but only to see him run."

On July 14th, Lull reaches Agate, and gains access to the bone hills:

> "We broke camp early ... and very soon came to Bush's over the divide. From here we drove for a way on the high plain but soon came to a draw down which we drove to the Niobrara River .... We camped here for dinner, then drove on to Cook's ranch.... Mrs. Barbour and daughter were there but not the Messrs Cook .... Dr. Barbour saw us for a moment as he was called east and offered us a share of his quarry beyond where his boys have stripped."

Lull recorded his Agate field work in a daily journal, and these entries show that the Yale party worked both on University Hill and at the Stenomylus Quarry of Amherst College. The complete text of the journal discussing the work at Agate can be found in the Peabody Museum archives, Yale University, New Haven. Lull's field journal remains the only written account of the Yale excavation at Agate in 1908, and is an entertaining, unpretentious, even humorous account, unusual in its candor for a field diary of that time.

On July 15th, the party dug some prospect holes at University Quarry but located no bones. The next day, Lull and Gibb discovered that Barbour's bone layer continued into their portion of the quarry. Blasting on July 17th removed much rock overburden from the site. On July 18th, "by dint of strenuous efforts we cleaned up a goodly portion of our area finding protruding bone in two places on the bone layer floor. Sent off one very efficient 3 stick blast so that we removed a huge heap of rock." Excavation on July 20th was not productive, only fragmented bone appearing. By July 22nd, the working floor of the Yale quarry was cleared of the dynamited rock using horse and scraper: "After lunch we started to work and the first shovel stroke laid bare an upper jaw of rhinoceros right under where our stone pile [the dynamited rubble] had been. I then proceeded with care and laid bare the finest kind of a bone bed fairly teeming with bone."

This concentration of bone was located at the south end of University Quarry, almost certainly restricted to Sections 15, 16, and 17. Possibly the work would have extended north as far as Sections 13-14 on the west side of the quarry, and as far south as Sections 18 to 20 (Peterson [1909, Fig. 28] indicates that University Quarry included 20 sections, each five feet long, whereas Barbour's field notes show only 16 sections, including no record of the four southern Sections 17-20. According to Peterson, Sections 17-20 would have been largely barren of bone, so Barbour probably did not think it necessary to plot them.). The bone layer in Sections 16-17 depicted in Peterson's cross-section of University Quarry (Fig. 3.39) is almost surely the area worked by Lull and Gibb.

The relationship of the Lull-Gibb excavation to Barbour's detailed quarry map (Map I) was not recorded by either Barbour or Lull. The best evidence as to the placement of the Yale excavation is from three sources: (1) Barbour's quarry map (Map I); (2) Lull's Agate journal of 1908; (3) Peterson's (1909) cross-section of University Quarry. Barbour's map shows that Yale worked at the south end of University Quarry because several slabs and other bones from the south end are listed in Barbour's notes as having been excavated by Gibb, and the division of the large entelodont occurred at the south end of the quarry in the same area. Lull's journal notes that the Yale men were to work in the area "beyond where his boys have stripped"; in all photographs of University Quarry, the north terminus is the same -- a west-protruding mass of rock capped by hard calcium carbonate-cemented ledges. The only work area available to Lull was at the south end of the quarry. Furthermore, the eventual playing out of the bones, mentioned by Lull, indicates that Lull reached the channel margin where the bone bed ended. Finally, Peterson's cross-section plainly shows one well-defined lens of the bone layer in Sections 16-17 that is not shown on Barbour's map of his excavation; this lens is to the south of the area worked by Nebraska at the extreme southern end of the quarry. It is the most probable site of Yale's effort.

Bones of the small rhinoceros _Menoceras_ and the chalicothere _Moropus_ are reported by Lull to have come from the excavation. Lull worked daily to expose and remove bones from July 23rd through 29th, noticing that many of the _Menoceras_ bones belonged to juvenile individuals. Part of the quarry floor was taken out as large blocks, the largest of which appears to be slab #77. Slab #77 according to Lull contained juvenile rhinoceros bones. A sketch of these blocks in position in the quarry was included in Lull's

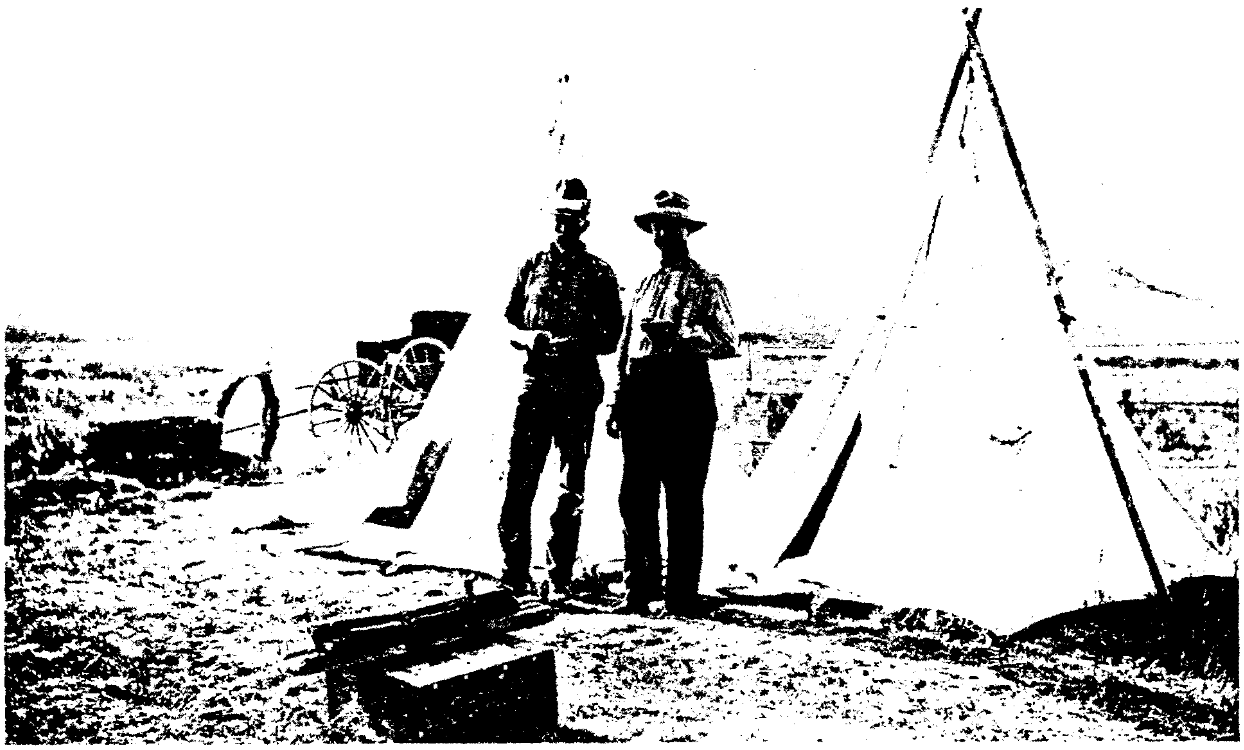


Fig. 3.40. R.S. Lull (left) and Hugh Gibb (right) outside their tents in the Niobrara valley at Agate in 1908. The Yale men worked the south end of University Quarry on University Hill, by the invitation of E.H. Barbour and the Cook family.

Fig. 3.41. The Amherst College party of 1908: from left to right, Leonard, F.B. Loomis, Blanchard, Wiltsie, and Parmalee. The Amherst and Yale men worked together in southeast Wyoming prior to reaching Agate. At Agate, in 1908, Loomis and his men excavated Stenomylus Quarry, while Lull and Gibb worked in both University Quarry and, for a short time, in Stenomylus Quarry at the invitation of Loomis.

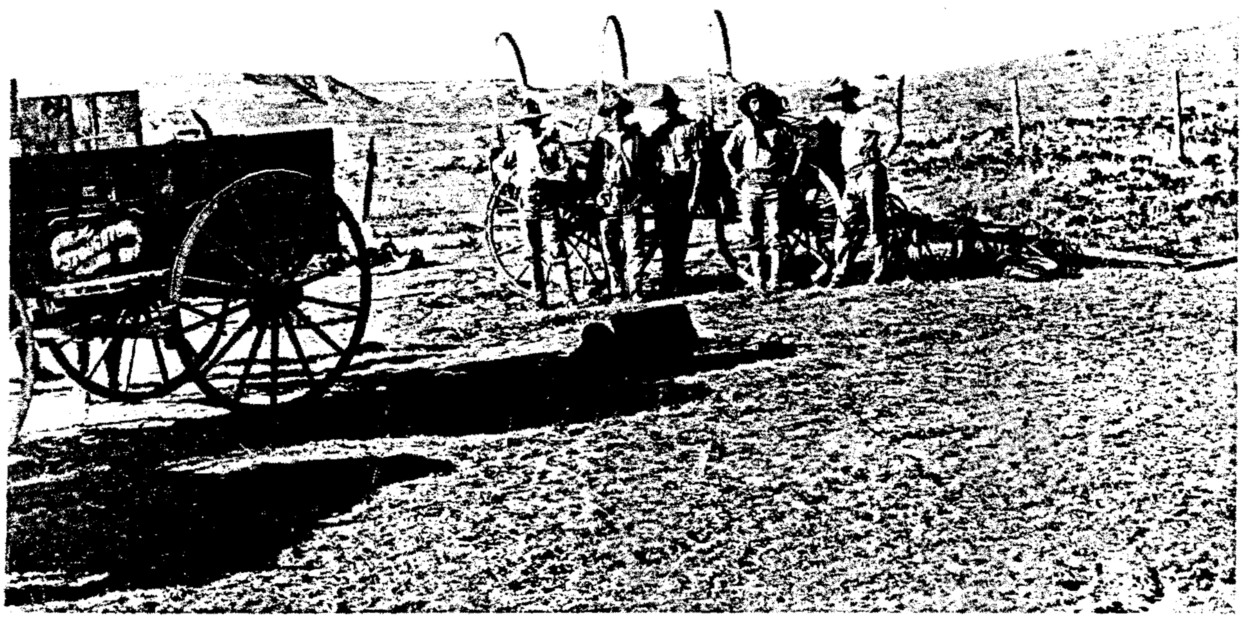


Fig. 3.42. The Amherst-Yale outfit at Agate in 1908, with the Amherst field party in front of their wagon. F.B. Loomis, Amherst leader and paleontologist, is at extreme right. Team and wagon were essential to the transport of fossils and supplies during the early years of excavation at Agate.

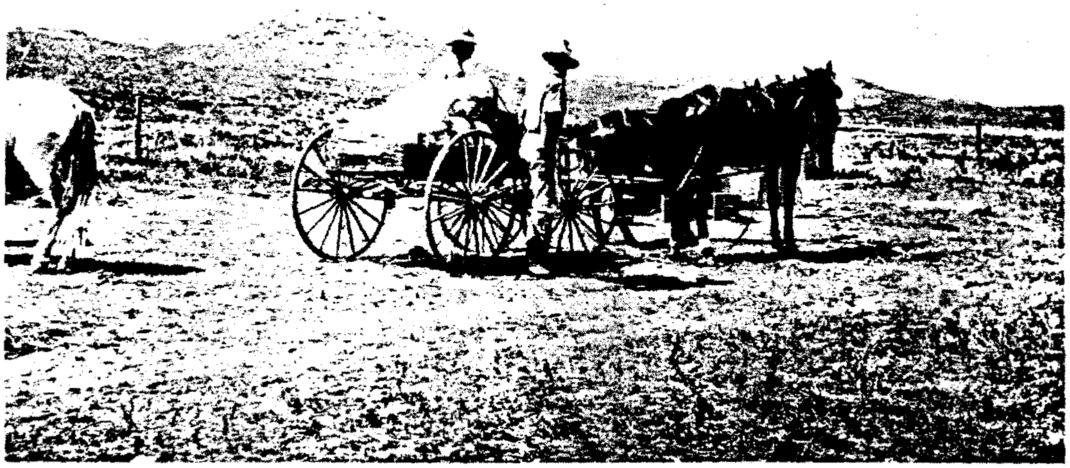


Fig. 3.43. R.S. Lull and Hugh Gibb depart Agate on August 28, 1908, ending the active work by Yale University in the main hills.

account book but unfortunately the map is not oriented to north, nor is it shown in relationship to any feature in the quarry. One large Agate block remains today in storage at the Yale Peabody Museum; it includes almost exclusively bones of juvenile rhinoceros. This block contained on its surface about 42 long bones of Menoceras (including innominates). Of these, 2 were adult with fused epiphyses, 32 were juvenile without epiphyses, 8 could not be determined. When I studied this slab at Yale in 1983, no field or catalogue number could be assigned to it, however it seems probable that it is #77 on the basis of Lull's field description.

On July 30th, Lull's luck came to an end: "A rather disappointing day in the quarry as the pocket seems to be running out, our splendid display of yesterday ceasing utterly. We cinched, tied up small pieces, and I drew a map of the quarry in order to help locate our blocks at home." During the next few days no new bone concentration came to light, thus on August 2nd, Lull went with Bill Thomson and F. B. Loomis to look for a good prospect at the Stenomylus Quarry. On August 5th, Lull and Gibb worked their newly assigned area at Stenomylus Quarry. However, the evening of the same day, Barbour approached Lull, who recorded the discussion in his journal: "In the evening we had a talk with Barbour who wants us to take another slice of his quarry toward where they are working, keeping all bone except such as may belong to the Dinohyus skeleton - a business proposition. I have decided to let Gibb return there tomorrow while I keep on with the camel prospect." This note explains the appearance of Gibb's name as a collector in Barbour's 1908 field list of specimens. Gibb apparently collected in Sections 14-15 near the east wall of the quarry in the area where the large Dinohyus was scattered.

Lull continued in the camel quarry until August 18th, and Gibb finished his work at University Quarry at about the same time. Remaining time was spent building and packing boxes to ship their fossils, and to collect some of the helical rodent burrow fills called devil's corkscrews. On August 28th, Lull and Gibb left Agate (Fig. 3.43), camping that evening at Andrews. The next day they traveled to Lusk to retrieve belongings from earlier in the summer, and that afternoon began the journey to New Haven.

Fossil mammals collected by Lull and Gibb are preserved in the Yale Peabody Museum. Most bones have been prepared and removed from the field blocks. The largest remaining block is the slab believed to be #77. It measures about 4 by 8 feet, and contains two associated pairs of juvenile Menoceras lower jaws, two isolated juvenile Menoceras lower jaws, a pair of adult Moropus lower jaws and a damaged palate. Scattered around these jaws on the surface of the block are ribs, vertebrae, podials, metapodials, limb bones, phalanges, and sesamoids. If the slab is representative, then the bone assemblage is not far removed from the original skeletons, but is fully disarticulated, and locally distributed. At least four juvenile Menoceras can be confirmed on the basis of lower jaws, corresponding to Lull's journal wherein many juvenile rhinoceros were excavated. A count of all Menoceras limb bones and metapodials (including innominates) on the slab shows that most are devoid of epiphyses. There are no obvious associations of skeletal parts other than the above pairs of lower jaws. Many adult bones belong to chalicothere.

Packing of bones on the slab is not dense, but scattered in a fashion similar to Barbour's slabs from University Quarry. Steep inclinations of bones are uncommon, most bones lieing without any apparent inclination. Fragmented parts of skeletons occur: a glenoid region of a skull, a partial basicranium, part of an innominate, broken long bones. Abrasion of some bone surfaces seems slight (level 1), but a number of elements show level 2 abrasion (atlas, astragalus).

Much of the remaining Agate material stored in the Yale collection is Menoceras, and some bones remain in block or in parts of the original block. This material is not densely packed in the blocks of matrix that have survived, but is scattered (e.g., blocks 78, 98A, 177, 178, 189, 191). A small block marked #3033, Box 17, contains scattered elements indicating in many cases level 2 abrasion, and two bones attain level 3. Block 177 also has much broken and abraded bone including a juvenile Menoceras maxilla and a chalicothere proximal phalanx which show level 2 abrasion. Among the Yale fossils, many highly abraded bone fragments of small size occur. In summary, relative to the American Museum chalicothere quarry sample, the material excavated by Lull and Gibb from University Quarry is very scattered and much abraded, with level 2 abrasion not at all uncommon. In this respect, the Yale fossils are most like Barbour's fossils, indicating that scattered and worn skeletal parts are the rule in University Quarry.

The only mammal other than the small rhinoceros, chalicothere, and entelodont in the Yale Agate sample that I observed in 1983 was in block 108. Block 108 has only scattered bones in matrix, and includes a small proximal phalanx of a carnivore, the size of a small canid, isolated on the block's surface.

With the departure at the end of the field season of Yale, Amherst, the Carnegie and American museums, and the University of Nebraska, an initial phase in the exploration and development of the Agate quarries ended. The volume of fossil material secured by these institutions was sufficient to satisfy their immediate goals (Fig. 3.44). Yale, Amherst, and Carnegie did no further concentrated excavation in the Agate quarries. Osborn of the American Museum quietly cultivated the Cook family, offering Harold an opportunity to study paleontology in New York in the fall of 1908. Osborn knew that the American Museum lacked a rich sample of the Agate mammals which already had been obtained by Nebraska and

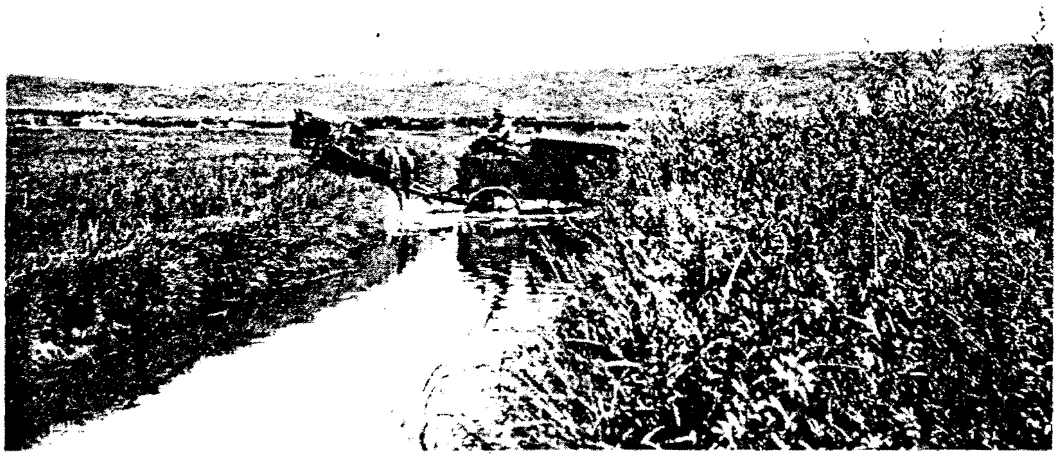


Fig. 3.44. Numerous heavy slabs from the bone bed and boxes packed with bones were hauled from the quarries by horse and wagon during the major excavations of 1905-1908 at the main Agate hills, then transported to the railroad at Andrews or Marsland, and shipped east.

Carnegie personnel. His patience in planning for the right moment to begin the work was to pay substantial dividends.

The year 1908 marked the end of the hegemony of the Carnegie Museum in the main hills. Holland in his annual report of 1909 concluded the Carnegie role with these remarks:

> "[Carnegie Quarry 1], located upon government land, but which last spring was entered upon by Mr. James H. Cook, has yielded us [lately] very little beyond what we already possessed in abundance. The fossils contained in it seem to represent principally species of which we now possess an abundant material, and it has seemed therefore wise ... to order the discontinuance of work at this particular point. While no doubt others who come after us may obtain much excellent material from this remarkably rich deposit, we have reached the conclusion that it is more to the profit of the Museum to abandon work there than to continue it. The animal which is most frequently encountered in this quarry is a species of small rhinoceros of which we already possess portions of some two hundred and fifty skeletons, and it does not appear desirable to add to their number."

With the Carnegie group removed from active excavation in the quarries, there was to be little future competition for the fossil resources. Two field seasons were to pass before major excavations would be developed in the main hills again.

3.2. 1909-1910: Interlude

Little paleontological work occurred at Agate in 1909, and none took place in 1910. Peterson returned in the summer of 1909 to continue his work at Stenomylus Quarry begun in 1908. To the 8 *Stenomylus* skeletons collected in 1908, he added complete or partial skeletons of an additional 19 individuals. Ironically, Peterson's work in the camel quarry prompted the ire of Osborn in much the same way that Holland had been disturbed by the American Museum work on Carnegie Hill. In October 1908, Osborn wrote James Cook:

> "You must have been surprised to hear from Mr. Thomson that Mr. Peterson started to do stripping of the Stenomylus quarry of the American Museum without asking our leave. This was pointed out to us by Harold, and after the stand taken by the Carnegie Museum I am surprised that they should have come into our territory this way. I have written Peterson a very mild letter in the matter."

On October 6, 1908, Osborn's letter reached Peterson:

> "Thomson has referred to me your desire to work in our Stenomylus quarry. I regret that I cannot extend permission

for this work. I should like to do it for you personally, as you know, but we shall certainly continue excavations in this quarry next season and clean it up thoroughly ourselves. We shall then be in a position to make an exchange with the Carnegie Museum and other museums."

Peterson replied in his own defense on October 13th:

"Regarding my being represented as desiring to work in your Stenomylus quarry, I regard as either a misunderstanding or a misrepresentation. The point is this: On leaving the quarry your men have not given any evidence (which is of utmost importance when more than one party is working the same field) of ever expecting to work the place again. During my absence of three or four days, I ordered my men to open the west face of the hill five or six feet further back, in order to ascertain whether or not there is more material in that portion of the hill. The boys went farther north, or, in on what Mr. Thomson claims, not having anything to guide them by; in fact I was myself ignorant of the boundary of your claim until Thomson spoke to me the evening they passed our camp. I expressed my sorrow to Thomson that the boys had gone too far north and also told him that since so much work had been done by my men I would like to go down to the bone layer and take out any specimens which might be found in the cut I had started, if it was not objectionable. But not to continue to work in your quarry after I found out that you intended to work there again.

"As a matter of fact, it is through my courtesy that your party was able to open that portion of the hill. Prof. Loomis told me to excavate anywhere I pleased after he and Prof. Lull got through. Loomis said I was the first party to ask him for permission. I, nevertheless, took the precaution to also ask Prof. Lull if I could continue the excavation when he got through, to which he agreed.

"I have now opened the west face of the hill southward from a certain large rock, which Thomson later claimed as your line, and find that I am not able to finish taking out material this fall. I have consequently caused the property to be fenced with barbwire and have also erected proper signboards to indicate our intention of working here another season."

Osborn apparently asked for W. D. Matthew's opinion of Peterson's reply, for a memo initialed by Matthew vigorously defends the American Museum position in the matter:

"This impresses me as a pretty poor defence. It seems a pity under the circumstances that Peterson hasn't the grace to apologize and close the incident. He practically admits all that Thomson has complained of -- and his sole defence is (1) That Loomis spoke to him (or he to Loomis) before he spoke to us about the quarry. This is quite true, but Loomis did not give or intend to give him any exclusive rights, and as soon as others asked him he laid out certain sections for each museum to work in -- all this before he stopped his own work. Peterson started work after Loomis finished, found his own section rather unprofitable, and occupied Lull's section by permission. Finding that unprofitable, he occupied Thomson's section without permission and while our party was still in the country, the season not ended and our boxes still in the quarry. It is perfect nonsense to talk about our being in the hill by his courtesy. He had no prior rights to us whatsoever. (2) That we did not post the quarry. It has never been done in any fossil quarry, as far as I know. The Agate Spring quarry was never posted. Would Peterson have thought that we had a right at any time when he had finished cleaning up a cut, to go into his quarry if he left it for a few days without asking him whether he intended to continue work? (3) That he did not know the boundary stone, 'subsequently claimed as limit by Thomson'. If he did not, he assuredly ought to have done so. The stone was not subsequently claimed but laid out by Loomis, and well known to all concerned. The real rights of course belong to the discoverer, old Cook, but Harold acquiesced in Loomis's division as a fair and decent arrangement. If Peterson acknowledged and regretted his mistake, I should wish to see the matter kept to ourselves and forgotten. It will not help his reputation to have the facts known outside."

To a photograph of the Stenomylus Quarry, which showed the Amherst, Yale, and American Museum cuts, Matthew appended the following note:

> "Peterson's cut in our quarry was directly back of the large block in the centre of the photograph .... It was not over at the edge next to Lull's opening, and his claim that the men 'encroached' on our quarry unknown to him is quite impossible. They opened a new cut in the middle of our quarry.

Matthew's righteous indignation, Osborn's patrician certitude in firmly excluding Peterson from the quarry, Holland's general failure to support his man -- one wonders at Peterson's apparent patience and fortitude in the face of the seemingly endless irritations visited upon him by events at Agate over the five years he worked in the quarries. To have made such a discovery when none had recognized its value, to have labored in the field to develop the site, mapping carefully blocks and bones, to have written during evenings and weekends to produce the first descriptions of the fossils, and then to have such conflicts materialize would have tried the best of men. Field paleontology was no picnic.

The incident, however, prompted a final resolution of the American Museum - Carnegie Museum conflict over the quarries, taking the form of a lengthy letter from Holland to Osborn on November 9, 1908:

"Mr. Peterson has handed me your letter addressed to him under date of November the 5th .... I desire to say that the matter concerning which you wrote [rights to work in Stenomylus Quarry] is thoroughly understood both by Mr. Peterson and myself. I have been upon the ground and know every inch of it. Your photographs are perfectly correct and your understanding as explained by these photographs is equally correct [Osborn had sent Peterson a photo of the quarry with the American museum claim indicated on it]. Mr. Peterson has enclosed with a wire fence that part of the hill upon which Messrs. Loomis and Lull have worked. This after a full and distinct understanding with them in reference to the whole matter. The fence stops at what Mr. Thomson designated as the 'big rock' and leaves your opening unenclosed....

"In reference to the quarry on what Barbour has designated as 'Carnegie Hill', in which we have been working since 1904, I desire to say to you that our work in the past summer has resulted, as I hoped it would, and as I think you already know, in the recovery of the missing portions of the great skeleton of Moropus upon which I am preparing a lengthy and elaborate memoir. We also succeeded in recovering a quantity of other material which was needed in order to supplement our work. I was entirely reluctant, as you will recall, last spring to invite you or anyone else to enter the openings which we had made at Mr. Carnegie's expense in order to exploit the place, believing that to do so would be a highly unscientific procedure under the circumstances, which would possibly lead to the dispersion of bones belonging to the same individual. The correctness of my views is confirmed not only by what has happened in the course of our researches this year, but in what happened in Professor Barbour's quarry, he having invited Dr. Lull to sit down beside him and go to work in the same opening. Barbour recovered the skull and fore quarters of a fine specimen of Dinohyus, and Lull captured the hind quarters. The skull and fore limbs are in Lincoln, Nebraska, and the hind quarters at New Haven. I do not think that you can approve of accidents like this.

"Now, however, having accomplished our purpose, and having for four years worked in this quarry, I am prepared to say to you officially, as Mr. Carnegie's representative, that we are willing to turn over the quarry to you to proceed with it as you may deem best, with two reservations. First, every foot of the workings in this locality has been carefully mapped, and I shall publish a map showing the progress from year to year of the excavations in that hill, together with the approximate location of the specimens found there. I request you, if you undertake this work, to continue (in the interests of science) to map the same, so that additions may be made and as in future years the hill is uncovered we shall have a sort of topographical survey of the bone layer which will give, better than anything else possibly can, an idea of the position of the remains which have been buried in this quarry. The second condition which I feel like suggesting is this, that if at some future time it seems desirable for us to continue our work in such a way as not to interfere with work that you may have in hand, we may be allowed to amicably proceed.

"This quarry, as you know, was discovered by Mr. Peterson of our Museum. The bones which Mr. Cook discovered and to which Mr. Peterson was conducted were the bones contained in what we know as Quarry A in our Museum Catalogue, located some three hundred yards away from the hills, and was opened up by Mr. Peterson on the occasion of his first visit to the spot and quickly exhausted. This quarry lies at a somewhat lower level than the bone stratum in the buttes which Mr. Peterson discovered. It was only after Mr. Peterson had called Mr. Cook's attention to the existence of the bones in the buttes that he recalled that some years before he had observed fragments of bone in the talus and had thought at the time that they were the bones, as he expressed it, of 'Indians and horses.' These simple facts are worth remembering.

"I hope you will realize that in everything I say and have done I have been animated only, first, by a desire to serve the best interests of the Institution which I represent, the affairs of which I control; secondly, to promote science; and thirdly, to promote a hearty feeling of good will between the great Institution over which you preside and that which it is my honor to direct."

So much for good will between great institutions.

W. D. Matthew penned the only surviving reaction to this letter in the form of a memo:

"The American Museum never requested nor desired to 'enter the openings which we had made at Mr. Carnegie's expense', nor could the continuation of work upon its own quarry on the Carnegie Hill lead to any such results as Dr. Holland here professes to fear.... I have no doubt that Dr. Holland is aware that Mr. Cook has no intention of letting him work any more in that quarry. He does wisely therefore in yielding gracefully what he cannot possibly hold."

3.3. Albert Thomson and the American Museum: 1911 - 1923

During the period from 1911 through 1923, the American Museum vigorously pressed the excavation of Carnegie Hill. Under the field leadership of Bill Thomson, the field parties not only deepened and extended the Southwest Excavation (Map A, Map F), but also extended and further developed their original quarry on the north side of Carnegie Hill, first opened in 1907. The outstanding discovery of this period was the great sample of chalicotheres from the north end of the Southwest Excavation, which included complete or nearly complete skeletons of at least 17 individuals of *Moropus*. This group of *Moropus* remains today the most complete sample of a chalicothere population known in the world.

3.3.1. 1911 Excavation

Thomson and his men were at work in the Southwest Excavation by mid-June 1911 (Figs. 3.45, 3.46). The party included Charles Barner, Lewis Roberts, and Arthur Albertson. Work began at the south end of the quarry (Fig. 3.47), then progressed to the north. On June 16th, Thomson described the quarry dimensions to W. D. Matthew:

> "Well, we sure have a quarry opened that will probably keep me busy until the snow flies. The cut is about 17 ft. deep at the back, and a space of about 150 ft. long by 16 ft. wide of the bone-bearing level cleared for action. I have three good husky men, good workers, and am now training them in to dig bones, which is rather slow as I have to watch every move and keep impressing on them that they must go slowly and carefully. Am working them on one end of the quarry where the bones are not so thick."

Correspondence between Thomson and Matthew was frequent, and is supplemented by informative letters from W. K. Gregory, later to become a distinguished anatomist at the American Museum, but in August 1911 an assistant to Thomson in the quarry. These letters supply some of the best information on the nature of the bone bed in the Southwest Excavation, adding substantially to the earlier observations of O. A. Peterson.

> June 29, 1911
>
> "My dear Dr. Matthew:
>
> "Since writing you I have been carefully watching the new army of bone diggers I have at work. It is very slow as yet as the bones, especially vertebrae and ribs, are very delicate, and the matrix very hard.
>
> "Now it strikes me to get the best results the bones should be carefully cleaned up right in the quarry. We have at present five very good skulls of [*Menoceras*] and more or less skeleton material. But they were so mixed up that it is

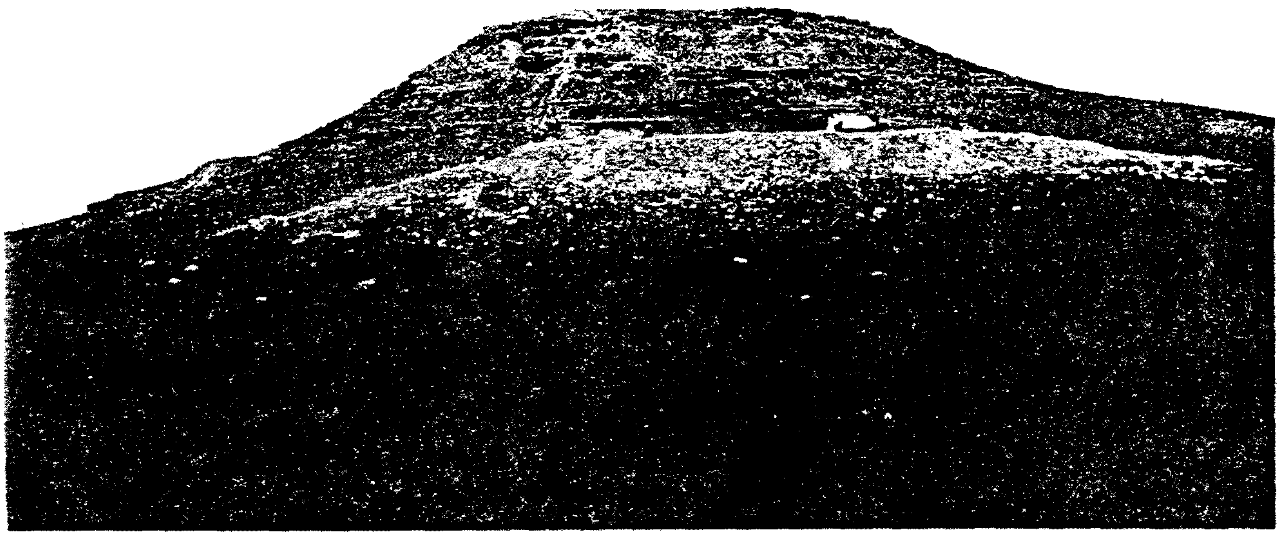


Fig. 3.45. American Museum party at work in 1911 in the Southwest Excavation on Carnegie Hill. The site had remained untouched since the field season of 1908. Holland of the Carnegie Museum relinquished the quarry to Osborn of the American Museum in November 1908. Work in 1911 was concentrated at the south end of the quarry cut.

Fig. 3.46. The American Museum excavation of 1911 at Carnegie Hill, looking north at the Southwest Excavation (note absence of any other quarries on the south side of the hill). Resistant ledge at top of hill is the Agate Limestone (See Map A).

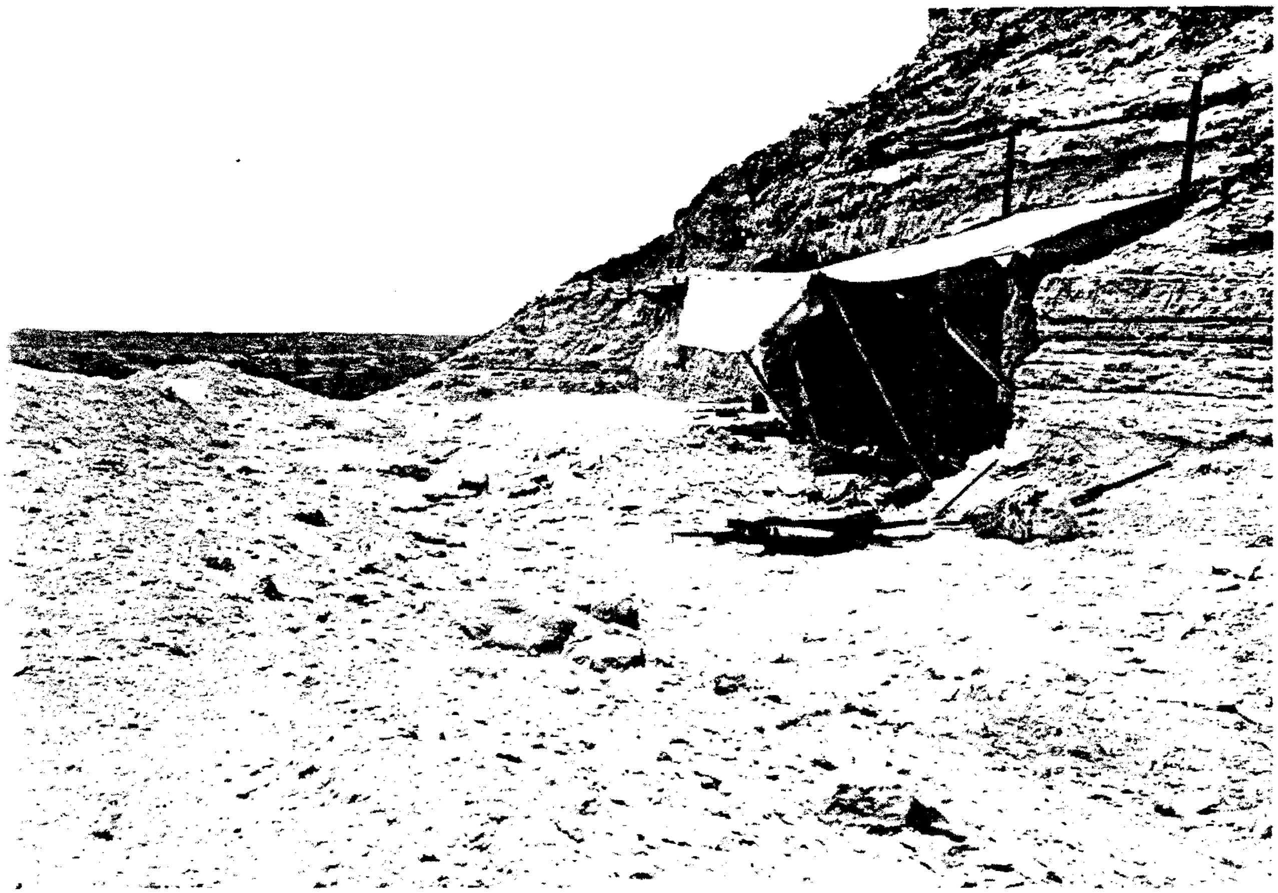


Fig. 3.47. American Museum quarry of 1911 at the Southwest Excavation at Carnegie Hill, looking northwest. Although the quarry floor was cleared to the north end, most of the work of the 1911 season was carried out at the south end where the shelter has been erected (see Map F). Here numerous rhinoceros bones were discovered (see Map G). The flat unexcavated floor at the north end of the quarry was to become the 'Diceratherium bed' that produced many exhibit slabs of rhinoceros bones from 1912 to 1923.

Fig. 3.48. Bone distribution and orientation in 1911 in the American Museum quarry, Southwest Excavation, Carnegie Hill. Many steeply inclined bones occur in unstable orientations in the dense bone mass.

really impossible to tell which is which. We also have a fair Moropus hind limb. To clean up the bones here means a year's work in just what we have stripped. Labor is cheaper here than in N. Y. Am paying these men $35.00 per month and board. I have to exercise patience I tell you and I think I have two that are going to be fair bone diggers.

"What do you think of making a winter camp here. And just clean up the bones ready for mounting. Because we surely would save on the freight. I don't think much of taking out bones, where they are mixed up, in huge slabs."

As the summer progressed, Thomson reported in greater detail:

July 17, 1911

"My dear Dr. Matthew:

"Since writing you last I have exposed an area of bones of about 10 x 20 ft. There is surely a great mass of bones, nearly all [Menoceras] material. Only a very few Moropus limb and foot bones, and no Dinohyus material so far. In the space we have just exposed are 17 [Menoceras] skulls. Some have horns and others just a slight bump. I take it they are male and female. Jaws, vertebrae, ribs and limb bones in one great jumble, a regular bone yard. We have not succeeded in finding anything articulated, or that we can be positive of belonging together. The ribs and vertebrae are particularly difficult to save, as the matrix as far as we have gone is extremely hard, but I think it will become somewhat softer toward the west end. The taking up of these bones is a very difficult proposition, as I told you in my letter before, it's 'got me going south'. I can see that if they are taken out in slabs (that is, the section we have stripped, 17 x 125 ft. or more), it will require no end of storage space at the museum. And there is no telling when it would all be worked out. Working here during the winter, as I suggested before, would mean building comfortable quarters to work in, and I would also have to get my family out here. But in the end we would have only such material as we could use for exhibition and study.... You see I have four men at work and I have to cut expenses all I can, because I am afraid it is a long winded job to get a Moropus and Dinohyus skeleton or even a mountable skeleton of [Menoceras] unless it would be a composite which would mean taking no end of material."

Matthew's response was immediate:

July 20, 1911

"My dear Albert,

I think you will want to carry out the policy agreed upon before you left, of cleaning up your material sufficiently to ship it with little or no matrix. At present I don't see how we could make both ends meet for a winter camp .... This may well mean that you will not finish your cut this season. But the cut will be all right to work next year I should suppose - frost will not do any serious damage in one winter."

On July 23rd, Harold Cook further informed Matthew of progress in the quarry, and made a number of observations on the bone bed:

"So far there is not a great deal of *Moropus* exposed in the quarry, but this may be partly due to the fact that so far only a few feet square have been worked out in the bone bed, and the rest of the section exposed, is only exposed a few inches at the top of the layer. I have noticed that the large bones are largely *well down* in the layer. So far, one good femur, two tibiae, one practically complete tarsus, several foot bones and a pelvis (which may be *Dinohyus*) is about the extent of what *Moropus* material is taken out.... There are now over twenty fairly good skulls of [*Menoceras*] exposed, most of them are excellently preserved, except for the premaxillae, which are nearly always absent, separated by the suture from the maxillae, not broken off. There is enough good skeletal material in sight now for a few composite mounts, but there is distressingly little association that is at all *certain*. The bones are as thick as would well be possible to imagine, and the layer, where it is now being worked, is about eighteen inches thick. It is also very hard at this point, which makes slow work, but at least 75 out of the 100 feet stripped is soft sand rock, and will be much easier to work. Some of the bones in the hard white rock where work is now being done are quite fragile, as though they had weathered before petrifaction set in, while others are very hard. I suggested to Thomson that he clean up where he now is working, and then go to the other end of the quarry, if he wished to make a showing as to quantity of material in a short time, but he says he prefers to take up things clean as he goes."

These initial reports by Cook and Thomson indicate that the American Museum's eastward extension of the old Carnegie Quarry 1 was as rich in small rhinoceroses as the area originally exposed by Peterson and his associates. The large number of skulls suggests that the individual rhinoceroses are scattered throughout the new excavation in a pattern similar to Peterson's earlier mapping (see Map E). The skeletons lack articulation, the separated bones mixed together in a densely packed and thick layer about 1.5 feet thick, as in Peterson's earlier descriptions (Fig. 3.48). The bone bed is differentially cemented by spar calcite ($CaCO_3$) to produce very hard zones and soft uncemented areas, making excavation very difficult in the cemented zones of the quarry.

Thomson in 1911 began the mapping of the American Museum extension of Carnegie Quarry 1. Each season thereafter, he added the newly excavated quarry floor to his earlier map (Map F). The mapping was continued from 1911 until 1920 when the American Museum ended their effort in the Southwest Excavation on Carnegie Hill. On the basis of Thomson's work, Osborn prepared a map showing the American Museum excavations of 1911-1920. To this, he added the mapping of Carnegie Quarry 1 which Peterson had generously provided. Thus was assembled the most complete map of the work carried out in the Southwest Excavation, the largest of the Agate quarries, from 1904 through 1920. Osborn did not publish this map, for he intended it to appear with his study of the large chalicothere sample, which was never completed. The map, modified to clarify the distribution of fossil mammals in the Southwest Excavation, is reproduced here for the first time as Map G. Photographs from the American Museum work of 1911-1920 confirm its accuracy.

W. K. Gregory, a young assistant to Thomson in 1911, described the quarry and its fossil mammals in a letter to Osborn on August 6th:

> "This is my first Sunday in Agate this season and it offers an opportunity to tell you how we are getting on. Thomson has divided the 100 foot opening in the hill into 11 nine foot sections. Section 1, already cleaned up, yielded [Menoceras] and some Moropus. In section 2 some 25 [Menoceras] skulls now lie uncovered after several weeks work -- mingled in great confusion with lower jaws, vertebrae, ribs, limb bones. Practically no associations occur in this section. Moropus limb parts [are] scattered at intervals. No trace of Dinohyus.
>
> "Data for estimating our chances for good Moropus remains are as follows: (1) Moropus has been found in our section to the right [southeast end of quarry], in the Carnegie Quarry to the left [Carnegie Qu. 2], and in our old quarry on the other side of the hill. It is rare in section 2. Ten nine foot sections remain to be cleared and Harold [Cook] has found parts of Moropus near the surface in some of these. (2) [Moropus] has also been found in abundance in the Nebraska University quarry but is said to be rare everywhere else. As the country has been searched for years by Harold as well as by Matthew and Thomson, Loomis, Riggs, and others, we all think it inadvisable to do any more prospecting until after sections 3 to 11 have been explored.
>
> "The great problem is to get sections 3 to 11 cleared this season. The remains are packed in so thickly that progress has hitherto been very slow, especially with green men. Harold has been unwilling to see even inferior material sacrificed and as he is the owner of the quarry Thomson has had to respect his wishes as far as possible. But we think that some of the material should be sacrificed. It is hopeless to try for a composite skeleton of [Menoceras] in the sections already opened, for the remains are packed in in the greatest confusion, without association, and represent both sexes and several reputed species. But Harold has now consented to our taking out the skulls and better material and

sacrificing the rest, so that progress from now on will be faster."

On August 9th, Thomson wrote Matthew, reporting information similar to that communicated by Gregory, but adding observations on the topography of the quarry floor:

> "Moropus and Dinohyus are a scarce article yet but hope to be able to get some before the season is over. Am in hopes of running on to some in a few days as the bone layer has taken a slight downward dip to what promises to be a large pocket. We are making better progress now as we are through that awfully hard layer and not trying to save anything but skulls and jaws and associated material."

Thomson and Gregory make plain that the American Museum sample from Agate is biased toward skulls, jaws, and associated material. In any attempt at reconstruction of the rhinoceros population buried in the quarry, only the skulls and jaws could be used to derive such an estimate. Also, the existence of varied topography of the quarry floor suggests channels and pockets like those already shown to exist in University Quarry.

On August 25th, W. K. Gregory again described progress in the quarry to Matthew:

> "The 100 ft. cut in the hill has uncovered an area that is packed with many hundreds of bones, set in very thickly and at every angle. Of the eleven 9 ft. sections (each about 18 ft. from edge to wall), three have been entirely cleaned up and the fourth is now under way. The rhinoceros is still so abundant that wherever you begin to work four or five skulls will soon appear within arm's length, generally tangled badly with other bones, but with no associations of any importance. Limb bones and odd pieces of Dinohyus and Moropus occur at intervals and this morning a fine lower jaw of Dinohyus appeared. Thomson knows well that the big fellows are the only things that will pay for the expedition, but although it is very probable that they are to be found in this quarry, it may be difficult to bag them this season. If after many [Menoceras] skulls were taken out, the order should be given to slash the rhinoceros and 'sail after' the big fellows, they would doubtless appear much faster. But without express orders, Thomson would naturally be very loth to sacrifice fine material, however abundant. Even if such sacrifice were deemed advisable from the Museum's viewpoint, Thomson would still have to reckon with the owner of the quarry, who has very decided views against slashing good bones. Harold's understanding is that after the Museum has selected what it wants for exhibition etc., he is to have the duplicate material, and he hopes to acquire a large series of [Menoceras] skulls which he can exchange for material to build

up his own museum with. Thomson and I deem it advisable to do everything we can to please the Cooks, who have been most generous to the Museum.

"Progress toward securing the prizes has therefore been slow. It has not seemed advisable to prospect for them any further, for, apart from the country having been pretty thoroughly worked over, with very little Moropus or Dinohyus found except in these two hills, the indications all point toward their being still there. Also Thomson's men require constant supervision, because it would tax even skilled preparators to extricate the bones from the tangle in which they are found. As it is, we have to sacrifice ribs and odd vertebrae etc., or we should never get anywhere.

"I don't think that so far we have even secured materials for a satisfactory composite skeleton of [Menoceras], for the skulls show very pronounced differences (perhaps specific) and there are certainly not enough vertebrae taken out to select a series from. However after Harold has determined the species it ought to be worth something to have such a large series for the study of individual and other variation (more than fifty skulls have been taken up or are being taken up)."

Gregory's letter confirms or clarifies a number of important points: (1) the quarry sections are nine feet in length; (2) by the end of August 1911, only four of the 11 sections cleared by Thomson have been worked; (3) the bones exhibit pronounced inclinations from the horizontal, and are not flat-lying as at University Quarry on University Hill; (4) skulls are not concentrated in one spot, but are scattered throughout the excavation and are abundant, thus this area of the quarry is similar in its pattern of skull distribution to the pattern in the adjacent Carnegie Quarry 1 (see Map E); (5) the bones are disarticulated; (6) entelodont and chalicothere are present but rare in this section of the quarry; (7) ribs, vertebrae, and other bones were being destroyed to acquire skulls, jaws, and the more preferred material.

Matthew replied on August 29th to Harold Cook, making clear the Museum's goal at Agate:

"I am living in hopes that the quarry will turn up some good Moropus material before long -- but we will have to take our luck as it comes, and I am counting on your permission to continue the work another year if we fail to find it this season. Dinohyus is of course a gamble. The certainty of a really fine series of [Menoceras] equal to the great series of skulls which are used in differentiating modern species, is of the greatest scientific value, although it will not help our exhibition series like these other beasts would.

"As to the question of individual variation, it is undoubtedly very wide in certain races, and is said to be especially wide in large species. Skulls and skeletons are much more variable than teeth. I do not see any inherent improbability in a number of allied species coming together to a single watering place, where their bones would be preserved, although it would not be likely that they would herd together. I should be inclined to take the evidence as it stands when you have all your material together, without prejudice either for or against the making of new species. Where you are dealing with fragmentary material or an insufficient number of specimens, I think it is better to lean to the conservative side, strongly in proportion to the inadequacy of the data. But here, I think your data are really adequate for once in a lifetime, and undue conservation is as out of place as the opposite tendency."

So it was chalicotheres that the American Museum most wanted from the quarry. Their wish would eventually be fulfilled beyond all expectations, but in the interim, the sample of rhinoceros became the focus of the work, and at the same time, the best measure of variation in an extinct rhinoceros population. Variation would be estimated from the skulls and jaws, other material often sacrificed. Matthew concurred in this, writing Thomson to this effect in late August:

> "I am glad to hear you are getting so fine a series of [Menoceras] skulls, and think you are quite right not to attempt to get the skeleton materials from a packed mass of miscellaneous bones. There is every probability that you will, before finishing, obtain some associated or partly associated [Menoceras] at a point where the bones are not packed so close."

In early September, the men had good fortune in the quarry, finally discovering a skull and jaws of Dinohyus (Fig. 3.49). This entelodont was marked on Osborn's map of the quarry (Map G), and was given the American Museum No. 15866. As Map G shows, this entelodont was found only about 18 feet north and slightly east of the Carnegie Museum Dinohyus skeleton (CM 1594). Harold Cook wrote Matthew on September 2nd with the news: "Thomson has a splendid skull, jaws, atlas, axis, humerus, scapula, radio-ulna, etc. of Dinohyus! I think his chances for an associated skeleton are excellent! It is not quite as large as the Carnegie or Nebraska specimens, but I take it to be a female. It is beautifully preserved, so far as exposed."

Little mention is made by Cook, Gregory, or Thomson of any other mammals in the quarry other than rhinoceros, entelodont, and chalicothere. Thomson's field book of 1911 lists 28 skulls, 26 lower jaws and miscellaneous postcranial bones of Menoceras, the skull and jaws of Dinohyus, and some Moropus limb material. However, in the same letter in which he announced the discovery of Dinohyus, Cook alludes to the discovery of other mammals: "There are some other immense carnivores in the quarry which scrap has been found of, but none ... much larger than Borophagus or Dinocyon." If

Fig. 3.49. The skull and lower jaws of Dinohyus (AMNH 15866) found by the American Museum party in 1911 in the Southwest Excavation (see Map G for location of this entelodont in the quarry).

true, this statement would mean the discovery of carnivores of wolf to bear size, documented by rare isolated bones and teeth, but because Cook initially identified some entelodont teeth as large carnivores, we cannot be certain of these finds.

By September 5th, Thomson told Matthew that still no associated rhinoceros had been found. Thomson believed that the work should continue into a second field season in order to find more entelodont and chalicothere, and Matthew was in agreement. The fossils were left at Agate in Cook's care at the end of the 1911 field season. Preparation of many rhinoceros skulls was completed during the winter by Harold Cook and an assistant.

The sample secured by the American Museum in 1911 included the skulls of over 50 _Menoceras_, lower jaws, and much postcranial material. The entelodont skull and jaws, and isolated and infrequent chalicothere and entelodont bones, comprised the mammals other than rhinoceros discovered in 1911. The bones were densely packed in a layer as much as 1.5 feet thick, with no association and with many steeply inclined elements. The south end of the quarry, where most of the work was done, thus proves to be dominated by rhinoceros skeletons in both the Carnegie and American Museum areas. By the end of work in 1923, it would be evident that a mass of rhinoceros skeletons occupied the entire southern two-thirds of the Southwest Excavation.

Thomson left a field book at the American Museum in the archives of the Department of Vertebrate Paleontology entitled, _Expeditions in charge of Albert Thomson._ His work in the Rosebud beds of South Dakota (1906-07), at Agate (1908-1920), and in the Snake Creek beds in Sioux County (1918-1926) are represented in the book by field lists and important supplementary notes. However, field diaries kept annually by Thomson during the Agate years are preserved in the library of the Field Museum, Chicago. From these records, it is possible to confirm or establish several important points. The sections into which the quarry was divided during the American Museum extension of the Southwest Excavation were nine feet long, based on dimensions given in an original sketch by Thomson in the American Museum field book. Osborn later indicated a length of 8 feet for these sections in his unpublished map of the Southwest Excavation, and Gregory in a letter from Agate at one time said they were 10 feet in length. Also, by comparison of Gregory's letter, which describes the areas of the quarry where work was completed, with Thomson's map of the quarry sections, we can establish that most work in 1911 took place at the south end of the new American Museum cut of 1911, chiefly in sections 1-5. The north end of the cut was scraped to the bone layer, but not excavated, and this area (sections 6-10) can be seen as a slightly raised platform of rock in Figure 3.47. Thus in 1911 the working surface of the quarry was about 90 feet in length, 18 feet in width (see Map F). The quarry retained this general configuration in 1912, except for the chalicothere pocket cut into the north end of the quarry that produced the first specimens of the great Moropus sample.

Fossils from the 1911 quarry were sent to the American Museum where many are still part of the Agate collection; others were donated, exchanged, or sold to other museums and academic institutions throughout the world.

3.3.2. 1912 Excavation

In 1912 and all later seasons at Agate, Thomson kept a field diary in which he recorded his observations in the quarry and the daily progress of the work. These valuable documents only came to light in 1982 when they were given to the Field Museum in Chicago by Thomson's niece, Ella Miller Gregg (Mrs. Robert E. Gregg) of Boulder, Colorado. Mrs. Gregg was the daughter of the paleontologist Paul Miller, who had married Bill Thomson's sister. These diaries have supplied a wealth of detailed data on the excavation of the American Museum chalicothere quarry, the excavation of the north side of Carnegie Hill, and the opening of the American Museum Quarry of 1923 (South Excavation, Map A).

Bill Thomson resumed work in the Southwest Excavation at Carnegie Hill in July 1912, departing New York on July 2nd, and arriving at Agate by stage on July 6th. Work in the quarry took place between July 8th and October 8th, and was carried on by Thomson and Charles Barner, later assisted by a Mr. Newhouse. Dimensions of the quarry were essentially the same as in 1911. Thomson apparently worked the stripped but unexcavated bone layer at the north end of the quarry that had been exposed in 1911 (sections 6-11), securing some rhinoceros (Fig. 3.50). But the most exciting discovery prompted the development of a tunnel (Fig. 3.51) into the quarry wall in section 11 where the first chalicotheres of the great American Museum sample were found.

The 1911 back wall of the quarry was not disturbed in 1912. Work began at the north end of the quarry. Here on July 13th, numerous rhinoceros were uncovered. On July 15th, a skull and two limb bones, the first signs of Moropus, were discovered. During the remainder of July and into the first week of August, chalicothere continued to turn up at the north end of the quarry. On Aug. 1st, Thomson wrote Matthew about the finds:

> "We opened the quarry at the west end where the bones are just as numerous, but seem to be in a little better state of preservation and in much softer matrix. Our best find so far is some very good Moropus material belonging to one individual, which consists of the skull and one side of the lower jaw, 6 cervicals, 9 dorsals, 15 ribs, both scapulae, both humeri, both radii, one ulna, one metapodial, several carpals, and one claw. The chances are there is more in the bank. I am going to have a few shots put in and try for some

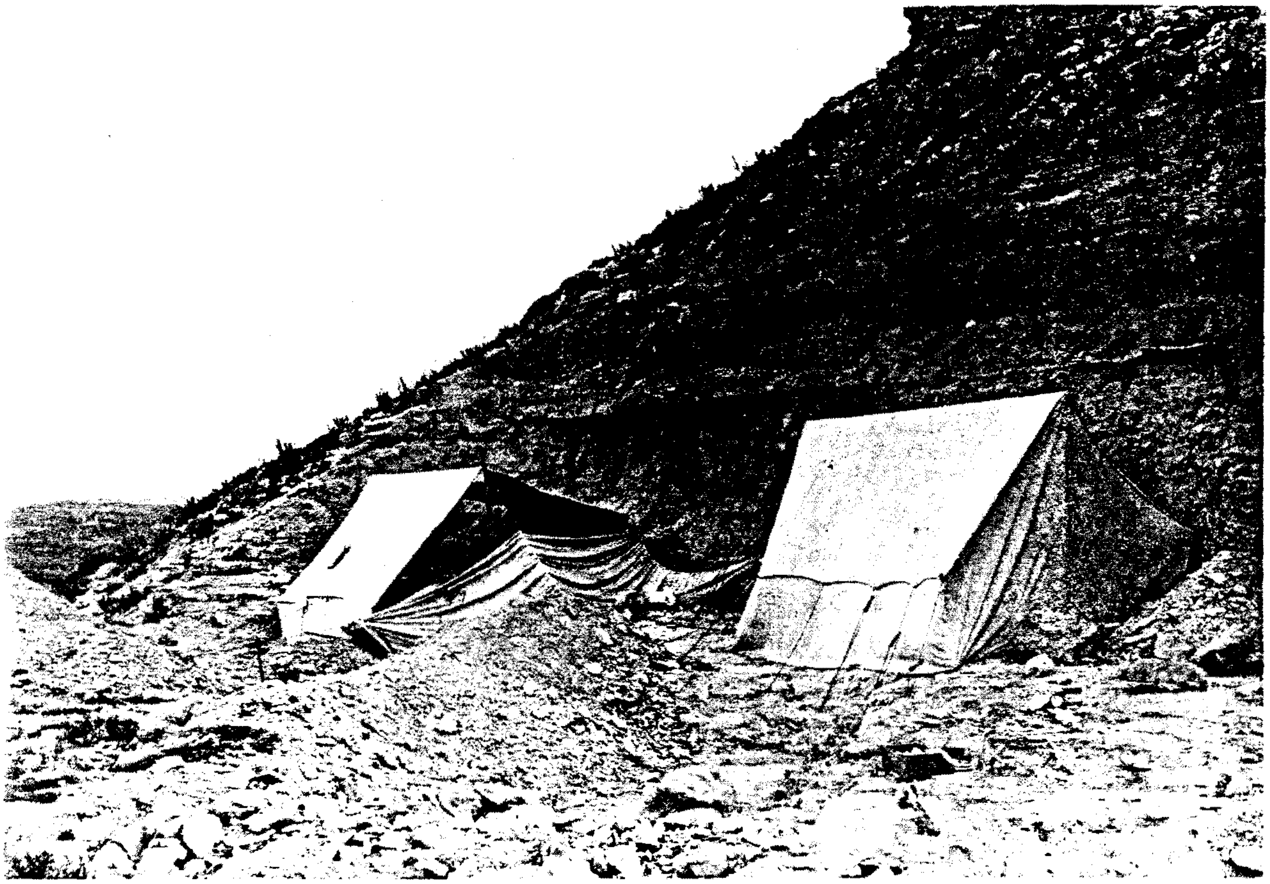


Fig. 3.50. American Museum excavation of 1912 in the Southwest Excavation, Carnegie Hill. The men worked the north end of the quarry cleared in 1911. The area beneath and south of the tent on the right is the 'Diceratherium bed' which produced primarily Menoceras bones (the right edge of the tent is nearly coincident with the north boundary of Section 6, Map F,G). The tent on the left shelters the extreme north end of the quarry where the first bones of the large Moropus sample were discovered in 1912: the excavation penetrated into the quarry's east wall to produce a tunnel in which more chalicothere bones were found (Figs. 3.51-3.52). The 1912 excavation terminates at the short north wall of the quarry seen behind the tent (left) just beyond the north boundary of Section 11 (Map F); this wall is identical to the north wall in 1911, showing that the quarry was not extended to the north in 1912.

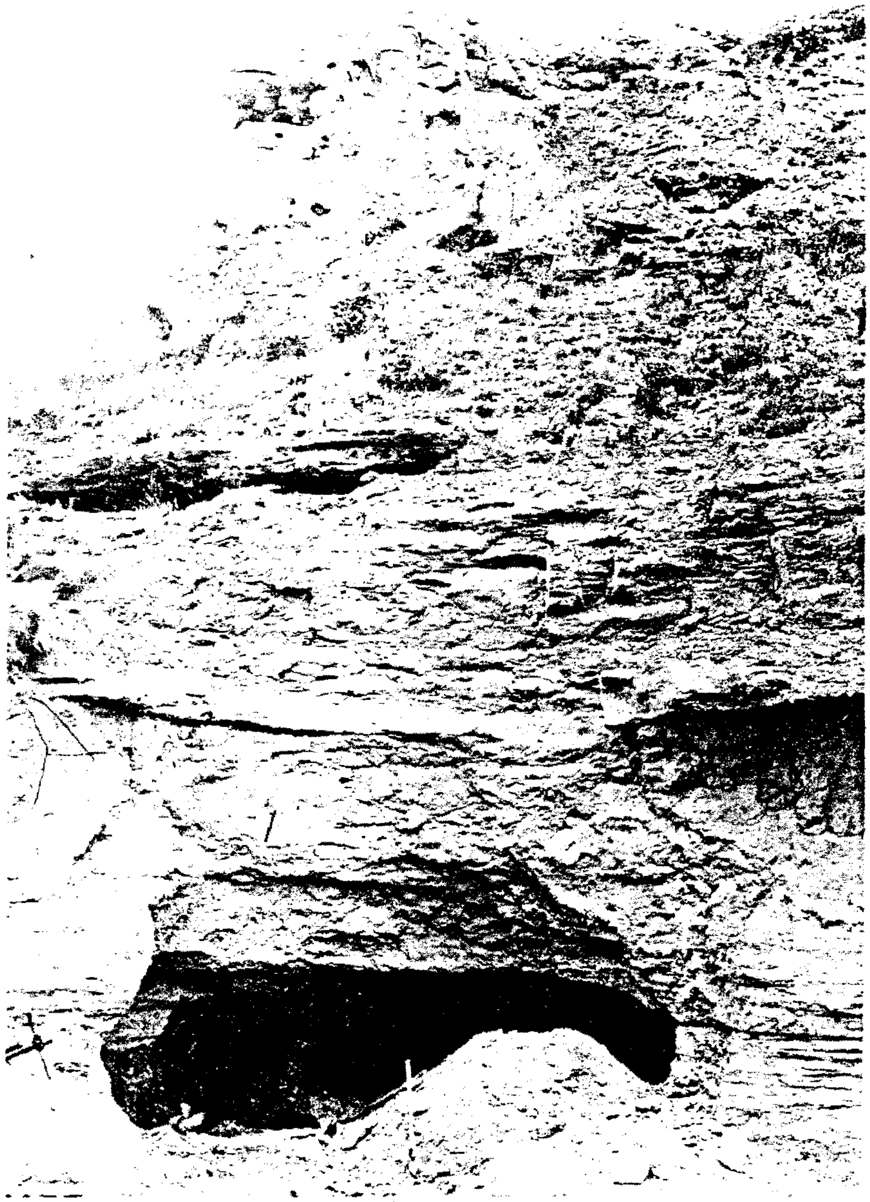


Fig. 3.51. Tunnel dug into the quarry wall in Section 11, Southwest Excavation, Carnegie Hill (see Fig. 3.50). This 1912 excavation produced the first bones of the great American Museum chalicothere sample concentrated at the north end of the quarry. Bone bed within the tunnel is shown in Fig. 3.52.

Fig. 3.52. Bones of large chalicotheres in the American Museum tunnel of 1912 at the north end of the Southwest Excavation, Carnegie Hill. This is the only known photograph of the bone bed during the 1912 work, taken by Albert Thomson. Note the disarticulated nature of most elements and the intermixed bones of rhinoceros.

more that may belong to this individual. I sincerely hope I may draw a 'Royal Flush' as I need it badly.

"There are only three of us at work yet, but at the same time we are making better progress than we did last year. I am running just as economically as possible. I have repaired the old spring wagon and the old harness so I think they will last this season, though it surely looks like a homesteader's outfit on its last legs. An auto would certainly be a great thing. Auto people run from here to Denver in ten hours. It would take us that many days."

The first chalicothere (AMNH 14377) was found close to the quarry wall, but as work continued Thomson found it necessary to blast at the north end of the quarry in order to follow the chalicothere remains into the wall. The men cleared much rock by blasting during the third week of August, and as excavation proceeded, more chalicothere appeared. During this interval, Newhouse quit the crew, leaving Barner and Thomson to continue the work. On August 21st, the second Moropus skull (AMNH 14376) was found, accompanied by a humerus, two ulnae, and a rib. For the remainder of August, chalicothere bones continued to appear: on August 28th, Thomson wrote, "Great find of Moropus ribs for 2nd specimen. Worked like fiends all day." Then on September 4th, Thomson uncovered a truly huge and well-preserved Moropus skull (AMNH 14375), together with a forelimb. Justifiably elated, Thomson wrote Matthew that evening:

"I am having pretty fair luck this year. Since writing you, we have gotten another skeleton of Moropus even better than the first. Good skull and jaws and, as near as I am able to make out, a complete vertebral column including cervicals and nearly all the ribs, both forelimbs, and some foot material. The pelvis I take it to be is just in sight and I hope the hind limbs will turn up. Today we were fortunate enough to get a humerus, ulna and radius, and part of the foot of a very large individual, and this evening just before we quit work the back of a very large skull [AMNH 14375] came into sight, but darkness prevented us from learning how good a one it is. [Menoceras] I have paid very little attention to so far.

"Granger spent Saturday and Sunday with me and we went over things pretty carefully.... Granger thought I was doing well, going at the quarry in the way I am doing. I am tunneling in a little instead of making a big cut. What lead me to tunneling was following in after the first Moropus. You see I have only one man now [Barner]. I had one other but he left when he saw a big pile of dirt to move after one of our blasts."

At the same time, Thomson also informed Osborn, giving him more detail on the composition of each chalicothere skeleton:

"Skeleton No. 1 [AMNH 14377] is skull and jaws, both fore limbs and a few foot bones, all the cervicals, eleven dorsals, two lumbars, and nineteen ribs. Skeleton No. 2 [AMNH 14376] has skull and jaws, vertebral series complete as far as I am able to tell, and I think all the ribs, both fore limbs, and more or less of the feet, pelvis just in sight in the bank, so there is some chance for hind limbs. Skeleton No. 3 [AMNH 14375] [has] skull and fore limb with some foot bones. I hope it turns out to be more complete than the first two. [Menoceras] I have not paid much attention to as Moropus is more important. Strange to say, Dinohyus material has hardly put in an appearance thus far. However, we will be busy from now until October taking care of what Moropus material is in sight."

Here were associated skeletons, not of rhinoceros (which would have been a good find in itself), but of the long-awaited chalicotheres! Nothing could have pleased Osborn more. On September 9th, Osborn cabled Thomson, "Letter fourth just received. Delighted. Full brass band playing in the laboratory." Of course, Thomson recognized that the value of the chalicotheres lay in their exhibition potential. But more significant, and little appreciated at the time, was the fact that these were surely the first remains of nearly complete mammals found together in the quarry since Peterson's discovery of the partially articulated chalicothere and entelodont from 1904-1908. These chalicotheres could not have been transported in a stream over a great distance or for a prolonged period of time. These animals had something to say about the origin of the Agate bone bed, and their message would be suitably amplified by the subsequent discovery of many additional individuals near them in the quarry from 1912-1920.

Success continued to plague Thomson. On September 9th, a fourth Moropus skull [AMNH 14378] was found, and on September 25th, a fifth skull [AMNH 14379] as well. Throughout the month, Moropus bones manifested themselves at a regular rate. By the time the fifth skull was discovered, the men had experienced their first snowfall of the season, yet the work continued for two more weeks. Finally, on October 8th, the quarry was closed; the wagons were loaded three days later with the fossils. On October 12th, the wagons left Agate for Harrison, about 30 miles north, which they reached in 6-7 hours with 2500 pounds of freight. Thomson returned to New York on October 20th, and was heartily congratulated by Osborn and Matthew. The fossils reached the museum on November 6th; by December 9th, the five skulls were prepared and restored, ready for study.

It was a season for chalicotheres, Thomson himself documenting that little in the way of rhinoceros material was collected. Once the Moropus was found, these skeletons became the focus of Thomson and Barner's work for the 1912 season. No statement about other mammals in the quarry appears in Thomson's field diary or letters.

Only a single photograph depicts the bone layer as it occurred in 1912 (Fig. 3.52): it illustrates chalicothere bones exposed in the bone bed within the tunnel in section 11. The bones are not evidently articulated, but may be in a few instances. A rhino skull lies near some of the large Moropus limb bones. A large limb bone appears to lie on top of other smaller bones. Most bones occur at about the same level, are scattered, and show no evident alignment in the deposit. What the remainder of the quarry floor looked like, we have no way of knowing.

Needless to say, the American Museum men were anxious to return in 1913. Matthew dusted off the dormant idea of a museum branch laboratory at Agate, presumably to encourage the interest of the Cook family in the excavations:

> Sept. 9, 1912
>
> "My dear Albert:
>
> I am enclosing a memorandum addressed to Harold Cook, specifying in detail what I understand our agreement to be, and what I think we ought to have for a fully adequate exhibition and study series from the Agate Quarry. Will you go over it carefully before giving it to him and discuss it afterwards with him and Mr. Cook. I would like also to have them understand that I have not at all abandoned the ideas that we talked over in 1908, of our having a sort of branch laboratory at Agate and using it as a centre for our field work in the later Tertiary, if we can get the funds to carry it on; and that I am counting on their cooperation in such a plan. The idea you remember was to build a shack and drive a well if they would dispose to us of a small bit of land for the purpose, and install you or some other member of the staff there permanently, with an assistant. We could not carry out the plan this year but it should be seriously considered for next year."

3.3.3. 1913 Excavation

Thomson returned to Agate in 1913, his aim the continued excavation and recovery of more individuals of the chalicothere Moropus for the American Museum. Leaving New York on June 3rd, Thomson reached Andrews, Nebraska, on June 7th, and rode the mail auto to Agate the same day. On June 8th, he inspected the quarry with Mr. Cook, and on the next day, work began by dynamiting rock overburden in the Moropus pocket at the north end of the quarry.

A road suitable for the museum's newly acquired automobile was built, leading to the quarries, and clearing of the quarry with team and scraper was started. By June 16th, Thomson had repaired the shack near the bone hills used as a camp headquarters, called by the men 'East Agate'. The field crew in 1913 included Bill Thomson, Charles Barner, and (from July 29) A. E. Anderson, with Messrs.

Montgomery and Roberts occasionally operating the teams and scrapers. During the next week, the men cleared and scraped the quarry floor. On June 26th, Thomson and Barner cleaned up the quarry in the morning, and began digging for bones for the first time that afternoon.

Thomson described the initial stages of work to Matthew on July 8th:

> "I should have written you some time ago but was anxious to get under way with the quarry work .... The first two weeks I was here we were very busy scraping away the loose dirt from the big blast. I had two teams on the job. The blast certainly did some execution, clearing away a strip about 10 by 50 ft. and averaged about 30 feet depth. From the tip of the new cut down to the bone layer is about 40 ft. With the new stripping and what we did not work last year, we have a very large space cleared, and if luck is with us we should get some Dinohyus material. [Rhinoceros] material for a composite skeleton can be had at any time. Dinohyus is the most important, and that is what I am searching for. Moropus we have, besides I have some of the missing parts for our large skeleton and a fair stagger toward another with a fair skull, also part of a skull of Dinohyus [AMNH 14442, an adult rostrum].
>
> "During the winter Mr. Barner cleaned up about 24 [Menoceras] skulls and other skeletal parts, making a total of about 46 skulls for two winters' work at a cost of about $400 or less than $10 each. The new excavation stands us about $225.
>
> "I have only Mr. Barner helping me yet, another man has promised to come in a few days, but whether he'll be of any use or not remains to be seen. The young man Harold had proved to be useless as most of them do, so I have decided not to waste any time looking for one, but go ahead with Mr. Barner....
>
> "The Auto is certainly a time saver to a bone outfit. It will go where a horse can, and can do it in less time, and carry a good load. [And to Osborn a few days later, Thomson wrote: "The Auto is a great thing -- bone digging is certainly modernized in this camp -- all we need is an orchestra."] We still have our team, they came in mighty handy scraping and saved us some money. Don't know when we can sell them now, as horses are a drug on the market here just at present."

Dimensions of the 1913 quarry were similar to those of 1911-1912 (Fig. 3. 53). However, the north end of the cut was enlarged in the search for more chalicothere remains (Map F). The 1913 excavation extended the quarry about 22 feet to the northwest, and up to 10 feet into the quarry wall toward the northeast. This extension took place as the men followed the chalicothere bones along the quarry floor. There is no doubt that Thomson simply began work where he had ceased the previous fall, continuing to explore

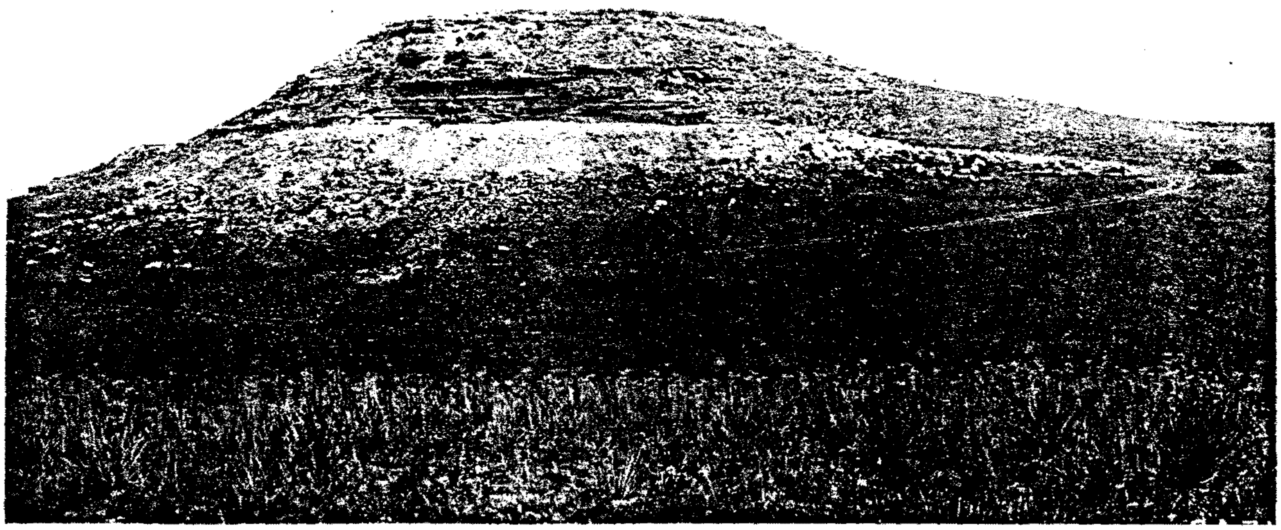


Fig. 3.53. The Southwest Excavation in 1913 during quarrying by the American Museum. Location of the chalicothere quarry occurs at the north end of the cut (left) where the man and the top of awning can be seen. First regular use of an automobile (far right) in the quarry work occurred in 1913.

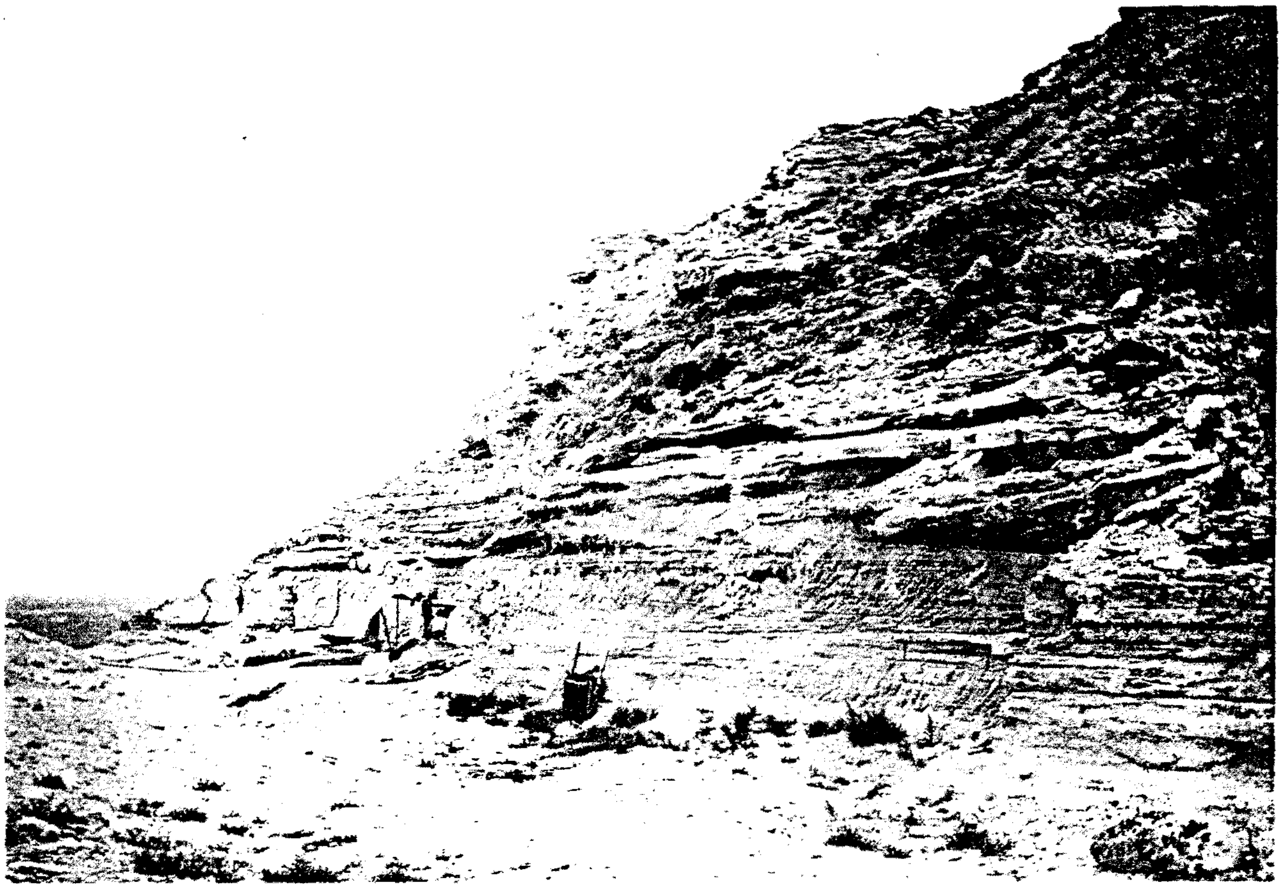


Fig. 3.54. The Southwest Excavation in 1913, looking north. Work was concentrated in the chalicothere quarry at the north end of the cut (where the awning and several people can be seen). The southern part of the cut is dormant.

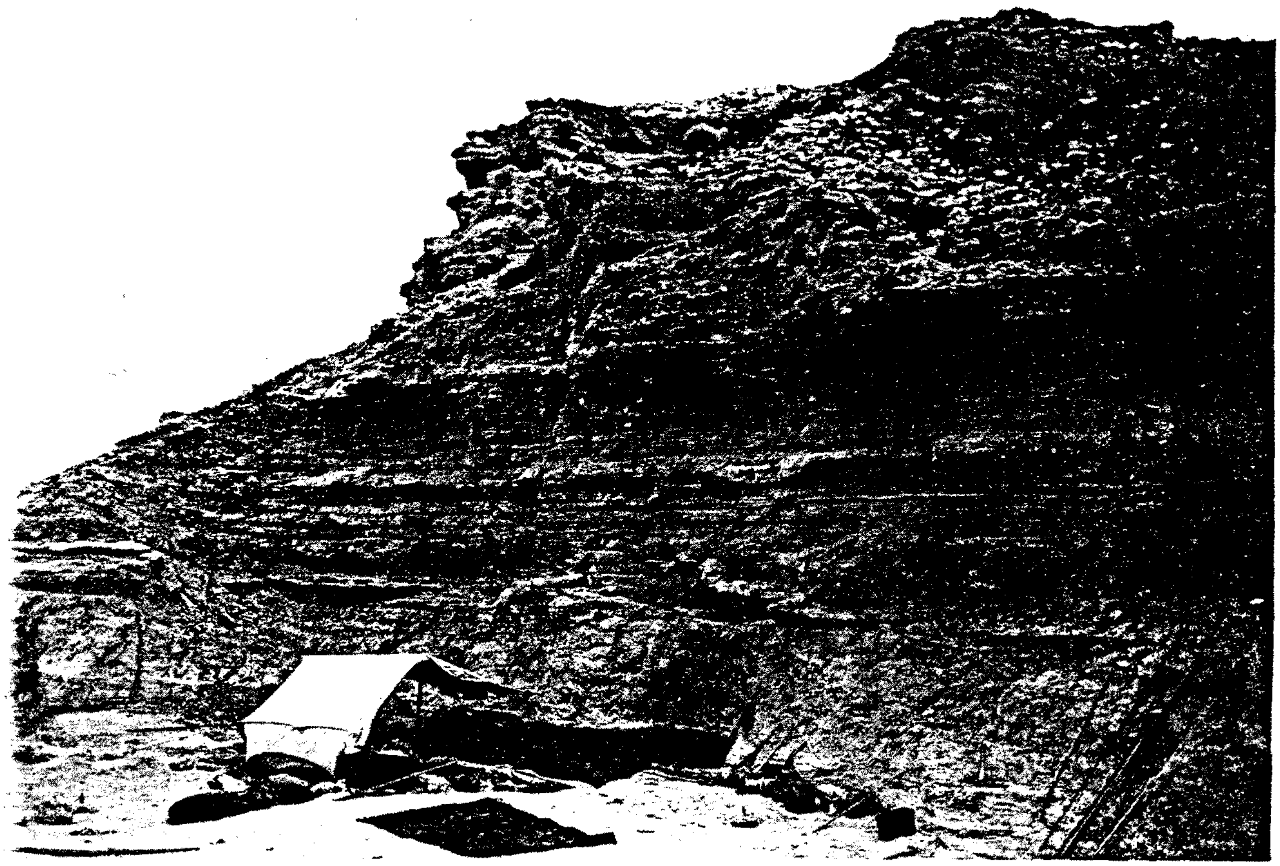


Fig. 3.55. The north end of the Southwest Excavation during work by the American Museum in 1913. The chalicothere pocket is present under the awning and continued into the quarry wall. The quarry flat in the foreground is the 'Diceratherium bed', rich in the bones of the small rhinoceros Menoceras, and has not yet been extensively worked.

Fig. 3.56. Bone bed in the chalicothere pocket of the American Museum, north end of the Southwest Excavation, 1913. Bones of numerous small rhinoceros are mixed with the larger bones of the chalicothere *Moropus*.

the exposed bone layer at the north end of the cut for more Moropus (Fig. 3.54). By the end of work in the fall of 1913, the length of the quarry was about 14 sections, each 9 feet in length, giving a total extent of 126 feet. The length of three sections (Nos. 12-14) had been added to the north end in addition to the original 11 sections of the 1911-1912 cut. The width of the quarry was increased in sections 7 through 12; in sections 10-12 where the chalicothere pocket was excavated, the quarry wall was pushed back 12 to 18 feet. Also, to the south of the chalicothere pocket, in sections 7 to 10, the cut was deepened, removing the 1911-1912 quarry wall (see Map F), and the bone bed exposed as a flat surface (Fig. 3.55).

The cleared surface south of the chalicothere pocket is the north end of the 'Diceratherium bed' noted on Map F. The 'Diceratherium bed' is Osborn's name for the southern part of the quarry bone bed packed with skeletons of the small rhinoceros Menoceras, previously called 'Diceratherium'(Tanner, 1969). The 'Diceratherium bed' of the American Museum was spatially continuous with the rhinoceros-rich area of the Carnegie Museum Quarry 1, thus the entire southern part of the Southwest Excavation was a jumbled terrain of rhinoceros skeletons. In the southern part of the quarry, only two significant entelodont specimens (AMNH 15866, CM 1594) and one chalicothere (CM 1604) skeleton were found by the American Museum and Carnegie parties. Almost all other bones belonged to Menoceras. [Although the formal name of the small Agate rhinoceros is now changed to Menoceras, I retain the term 'Diceratherium' for the bone bed, because of historical precedent.]

It is from the southern part of the quarry, the 'Diceratherium bed', that many North American institutions obtained blocks of the Agate bone layer. These blocks are dominated by bones of the small rhinoceros. As noted by Osborn on his map (Map F,G), many blocks were removed from the quarry between 1912 and 1923. In some cases, by means of photographs, maps, and correspondence, we can determine the exact location of a block in the 'Diceratherium bed': for example, the American Museum Agate block collected in 1919, today displayed in the Hall of Mammals, was removed from section 8 near the old 1911-1912 quarry wall. The Carnegie Museum Agate block (Block 70, Map E) was also collected from the same general area in Carnegie sections 14-15 in 1908. These blocks provide a firsthand knowledge of the bone layer in this part of the quarry.

By the end of the 1913 season, the pattern of bone distribution (Map G) in the Southwest Excavation was evident: the southern 9 sections of the quarry are dominated by a mass of Menoceras bones, mixed with occasional isolated bones of entelodont and chalicothere; the north end of the quarry (sections 10-12 in 1913, eventually 10-14 by 1920) contained many Moropus skeletons, mixed with some rhinoceros. Even at the south end of the quarry (sections 2-5), where two partial skeletons of Dinohyus (CM 1594, AMNH 15866) and the single individual of Moropus (CM 1604) had been found, their remains were surrounded by numerous rhinoceros bones.

Thomson's photographs of the bone bed in 1913 show only the chalicothere pocket at the north end of the quarry where their work was focused (Fig. 3.56). The chalicothere bones are isolated and jumbled together in unstable inclinations with many rhinoceros bones, so it is clear that the chalicotheres were mixed with Menoceras in the deposit. All elements of the skeleton can be recognized: vertebrae, ribs, limb bones, skulls, jaws, podials, girdle elements. These bones had sufficient time after death to disarticulate and disassociate, then become mixed with bones of another mammal in the sediment. No comment was provided by Thomson on the topography of the quarry floor, or on the barren area of the 1913 excavation exposed by Barner in sections 13-14 at the northwest end of the cut (Map F,G). There is no obvious relief seen in photographs of the site, nor any indication of the topography of the base of the bone bed.

Mammals found by the American Museum in 1913 were almost entirely chalicothere and rhinoceros. The only entelodont of record is marked on Osborn's map (Map G, AMNH 14442, a large adult rostrum) in section 12, found near the No. 6 skeleton of Moropus. Apparently no other entelodont remains accompanied the rostrum. One additional isolated entelodont foot bone was found in 1913, mentioned by Thomson in a letter to Matthew, so Dinohyus was very rare.

Moropus bones were first discovered by Thomson and Barner on June 27th and continued to turn up in the quarry on almost a daily schedule until October 2nd. Thomson on several occasions recorded the mixed nature of the deposit. On August 29th: "Worked at large individual of Moropus -- found another individual mixed in with it and much rhino material." On September 4th: "Blocking out Moropus but very difficult -- too much rhino material." And on September 10th: "Pegging away at the big Moropus blocks. But rhino interference causes slow progress." The density of the chalicothere-rhino bone mixture in places was evident: on September 9th, Thomson wrote, "Very difficult to get through for blocking. Too many Moropus bones."

On August 29th, Thomson detailed his quarry strategy to Matthew:

> "Well we are just swamped with Moropus material. I doubt if we will be able to get it all out this year. It is almost impossible to save any [rhinoceros] material while taking out Moropus. If we were to take out big slabs, we would destroy more or less Moropus material. As I think Moropus is vastly more important than rhinos, I am not taking too much pains [with] rhino material, because there is oceans of it that has no Moropus mixed with it and there is where I hope to get material for mounting. No Dinohyus has turned up yet, but we may be swamped with a pocket full of them some day, at least

it is to be hoped."

Near the end of the field season, Thomson summarized the important discoveries at the quarry:

> "We are trying our best to get out all Moropus material in sight .... I have two large blocks plastered containing parts of two or three individuals, [and] two more blocks ready to plaster, one containing more or less of a large individual with good skull and jaws. The other [block] contains the greater part of two young specimens--about 2/3 grown. And another [block] which seems to be a little different from the others, [including] a fairly good skull, both femora, both tibiae and fibulae, one or both scapulae, humeri, ulnae and radii, one side of pelvis, several vertebrae, many ribs and foot bones - this is only what we have taken out of this specimen so far - hope to find the greater part of it as the bones are beautiful. There are also two other Moropus specimens running in which I am fearing I may have to leave for next season. As for Dinohyus, I have only a palate and one foot bone. The rhinoceros material is a perfect nuisance where you are working on Moropus. A great deal of time is lost trying to save any of it, therefore I am not paying as much attention to it as I should, because Moropus skeletal material is surely more valuable.... And with what material I have this year, I am satisfied that we have the best and greatest variety of Moropus material in the world."

The last large block was plastered for removal from the quarry on October 6th, and the next week was occupied with assembling, packing, and wiring boxes for shipment of the fossils to New York. On October 15th, the quarry was closed, and the next day saw the men leave by automobile for Harrison, Nebraska. Thomson arrived in New York on October 25th, and spent much of the fall working up chalicothere from the quarry.

In his field notebook in the American Museum archives, Thomson recorded a field number for each of his chalicotheres during the 1912 through 1920 seasons. The complete listing is presented verbatim in Appendix H. In 1913, the chalicotheres were assigned Nos. 6 to 12. In this instance, Thomson was unsure of the exact number of individuals present in the field, and of the bone associations as well. No. 6 included two individuals, possibly three; No. 7 included the skull and most of the skeleton of a single individual; No. 8 included the skull, jaws, and skeleton of a large animal (some bones mixed with No. 8 were numbered 8A and were said to belong to No. 11); No. 9 belonged to an individual not fully excavated and so much remained in quarry; No. 10 comprised two young animals; No. 11 was a set of jaws, the remainder of the skeleton left for the next season; No. 12 included foot bones and some ribs, with the remainder left for the next season. If we take Thomson's count at face value, he would have discovered the remains of 9-10 chalicotheres. If added to the Nos. 1 to 5 found in 1912, this would give 14-15 individuals, but Nos. 4-5 were isolated skulls which could belong to skeletons found in 1913, so the best estimate of total individuals found by the end of the 1913 season was 12 to 13 animals.

The 1913 season seems to mark the inception of the idea to sell some of the Moropus skeletons from the quarry. Unfortunately, this would result in the dispersal of this unique population to many institutions, making a comparative study difficult. Matthew mentions the possibility to Thomson on August 4th:

> "Professor Osborn expects to pay you a visit and will have an important matter to discuss with you and Harold [Cook]. Dr. Drevermann of the Senckenburg Museum [Germany] is very anxious to obtain a skeleton of Moropus, and of course under the terms of our agreement with Harold we have not the right to sell or exchange even if other skeletons should turn up. Harold I know wants to have a skeleton or characteristic parts for his own museum, but if there should also be enough to supply Drevermann, we might come to some agreement with Harold about the matter. I should not feel that it was altogether proper for Harold to sell specimens collected at our expense and put the money in his pocket unconditionally. Nor do I suppose that he would wish to do so. But if a skeleton were sold to the Senckenberg Museum and the money applied to putting up a field laboratory at Agate and continuing preparation work there, ... it would seem right to me. The matter is worth thinking over rather carefully, and Professor Osborn and Mr. Cook will no doubt agree upon some fair solution. We have pretty nearly all we need of Moropus for exhibition and while we could use a good deal more for study we don't want to be hoggish about it."

3.3.4. 1914 Excavation

The goal of the 1914 field work on Carnegie Hill was to collect the remaining chalicothere skeletons that had been left at the quarry at the end of the 1913 season. With this in mind, Bill Thomson left the east by train on June 27th after spending much of the spring of 1914 and the previous winter preparing the Moropus specimens collected in 1913. Thomson reached Agate on July 1st, a broiling hot day that was to set the tone for the remainder of the field season. During the next few days, he examined the situation at the quarry and set up his camp. His assistant, Charles Barner, visited him but was working for W. J. Sinclair, a Princeton University paleontologist who was then in the Agate area.

Sinclair had arrived at Agate on June 12th, in his words "after a wild ride across the plains in a cow-punching auto." He was controversial, not known for polish or tact. He had hired both

Barner and A. C. Whitford to work the Snake Creek beds in early summer, later developing a small section of the Southwest Excavation in order to obtain a few small rhinoceras slabs for Princeton. This small excavation in the Diceratherium bed was designated as Princeton Locality 1002A.

Thomson began work in the chalicothere quarry on July 6th, assisted by William Stein, and by the next day had uncovered new Moropus material. On July 8th, the first chalicothere skull of the 1914 season was discovered, as well as many other Moropus bones. Two days later, just prior to the entry of the party into the quarry for the day's work, 3 tons of the cliff above the site caved in, emphasizing the need to remove the overburden above the tunnels in which the bones occurred. Earlier, in 1913, Osborn had cautioned Thomson about the height of cliff that was developing above the workmen as excavation progressed. When the debris was cleared, more chalicothere appeared, seemingly inexhaustible, and the temperature reached 110 degrees as the bones were excavated. On July 13th, the vertebrate paleontologist E. C. Case from the University of Michigan visited the quarry; in 1922, Michigan would acquire a block of Agate bones from the bone bed in the Southwest Excavation, but at the time Case and an assistant were on other business. On July 14th, Thomson wrote Matthew of what had been accomplished:

> "Things here are running along smoothly, but it is very hot and dry out here this year. We are finding some more Moropus material. We have a skull, but like the rest, [it] has the front all broken away, two sets of hind limbs and pelvis, some foot bones and quite a number of vertebrae and ribs. However, this is only one of last year's prospects that we are working on yet. So I think we will have all we can do to get out what we had planned. Billy [Stein] works patiently but does not understand much about these bones yet. I wish I had Barner and may take him on when Sinclair gets through. At present Sinclair is working down towards Marsland [Nebraska], but am expecting him back here any day as Harold [Cook] has given him permission to take out a rhinoceros slab, and then he expects to work a little in the camel [Stenomylus] quarry.... Do you think there is any possible chance of our working the quarry another year in case we do not get a Dinohyus this season? I have not heard a word about the Agate Museum. The Cooks are in the best of spirits and Mr. Cook visits us very often - he seems to enjoy looking at the Moropus bones."

Dimensions of the Southwest Excavation were only slightly increased in 1914. As Map F indicates, work was restricted to the chalicothere quarry at the north end of the cut. Tunnels were extended into the bank, following the Moropus skeletons. Two tunnels were dug into the hill, one toward the north, and the other toward the south (Fig. 3.57). The north tunnel (Fig. 3.58) was the larger, and included the skeletons of chalicotheres Nos. 9, 9A, and

11 in sections 12-13. The south tunnel (Fig. 3.57, right side) produced chalicothere No. 12 in section 10. Photographs show that by 1914 nearly 40 feet of rock overburden towered over the excavation. By the end of the 1914 season, the quarry was about 125 feet long, and averaged about 20 feet in width. It was widest at the chalicothere site on the north end where it attained 40 feet. The quarry maintained these dimensions until the 1920 excavation when the north end of the cut was even further expanded.

In late July, Sinclair's party arrived at Agate and established a camp. On July 27th, he began to excavate slabs of rhinoceros bones from the Southwest Excavation with Harold Cook's encouragement. The exact location of Sinclair's work is established by 2 photographs in his 1914 Princeton field journal. He excavated in the 'Diceratherium bed' (Map F,G), which had been previously scraped down to the bone layer by Thomson, but in 1914 remained largely unexplored. Sinclair continued work until August 11th, leaving by train on August 17th. One slab containing primarily <u>Menoceras</u> survives today, housed in the Princeton Department of Geology, where there is also a mounted <u>Menoceras</u> skeleton and several trays of prepared bones.

While Sinclair dug rhinoceros, Thomson continued to uncover more and more <u>Moropus</u>, by now an embarassment of riches. On August 4th, he described the specimens to Matthew, also intimating that some conflict existed with Sinclair's party in the quarry:

> "Things at the quarry are progressing rapidly. Moropus material galore, but the beasts are making us tunnel now. Instead of two specimens of last year's prospects, it is the greater part of four individuals. We have one skull but need three more which we hope to find in a day or so. Two of these specimens seem to be the smaller type [at that time believed to be a smaller species by Holland and Peterson, but now regarded as females]. The tunnel work is hard but we hope to get through with it in a week or ten days. I have another of last year's prospects that I have not looked into yet. I am not paying any attention to rhino material. If I did, I'd be here until my end. No sign of Dinohyus as yet.
>
> "Sinclair has taken out two or three small slabs of rhino goods, and now he is going after Daemonelix, just a specimen or two, then he's going to try for a Stenomylus skeleton.
>
> "I hope I can get through by Sept. 1st so I can get away from here. It is hard on my nervous system to be diplomatic. I am planning on getting the car away on a prospecting trip.
>
> "Is Professor Osborn coming out here this year, have you heard? I wish he would or could get out here while Sinclair is here....
>
> "Everybody out here is watching the European war mess, that is a terrible thing....
>
> "By Sept. 1st we will surely have all the Moropus we want. So I should think we could make some arrangement to get

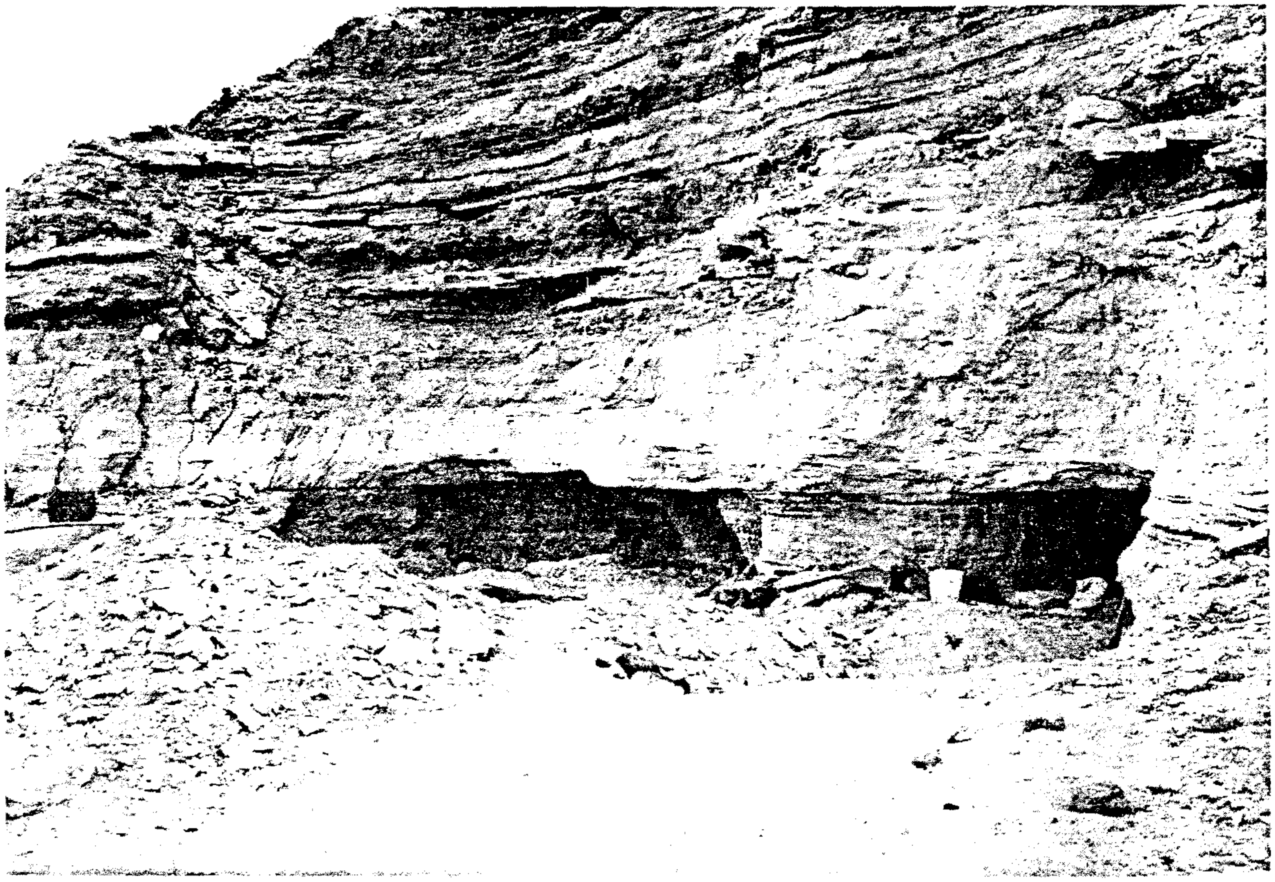


Fig. 3.57. American Museum chalicothere quarry in 1914 at the north end of the Southwest Excavation on Carnegie Hill. Two tunnels were developed that followed *Moropus* bones into the hill. Note the primarily horizontally stratified fluvial sediments in the lower part of the hill.

Fig. 3.58. The bone bed in the American Museum chalicothere quarry of 1914 at Carnegie Hill (for distant view, see Fig. 3.57). Many large Moropus bones are visible, and also a male rhinoceros skull in unstable orientation (rear center). The bones are generally disarticulated, and the larger bones are not steeply inclined from the horizontal.

Dinohyus, without going back under the hill. We have a space cleared 20 x 100 ft. which may turn up Dinohyus but we would have to prospect it all and that means having that area of exposed rhinoceroses."

On August 7th, Thomson wrote Osborn:

"I am working just as rapidly as I know how, as I want to get all the Moropus material I can while the getting is good. We have four skeletons, more [or] less complete, two [skeletons] out [of the rock], but only one skull and jaws so far, though there is a good chance for a couple more skulls. The specimens we are working on now are running into the bank and we are tunneling after them. Two of these are quite small individuals, but adult. One is as large as the one we took out last season if not larger.

"One of the Moropus prospects left from last season I have not had time to look into yet, but will as soon as we get the others out. I have seen no sign of Dinohyus as yet, and if I put in another season searching for the beast without results, I'll be a fit subject for some 'Bug House'. The heat this season is something terrible, from 95 to 110 degrees under the awning nearly every day, and my camp this year is far from as comfortable as last year."

On August 12th, after Sinclair's departure, Charles Barner and A. C. Whitford, who had been employed by Sinclair, went to work for Thomson, giving the American Museum a four man crew.

On August 14th, Matthew wrote Thomson, revealing that the politics of quarry work at Agate with Sinclair might have been strained:

"I am glad to hear things are going on well at the quarry. We certainly will have a good supply of Moropus when you get through. It will be a good thing if you can get in your little reconnaissance trip, and doubtless will be a relief to you to get away from the quarry. If practicable it would be better to leave the auto over the winter at the Cooks if they are willing to house it. If you leave it elsewhere, you run some risk of offending them by doing so, and that is what Professor Osborn is especially anxious to avoid. I spoke to him about it and he thought it would be better to keep it at Agate over winter even if you do risk its being put out of commission. I know this comes hard on anyone who is as careful of his equipment as you are, but I am pretty sure that the Professor would rather see the auto destroyed than the Cooks seriously offended at the Museum.

"As to Dinohyus, I am not disappointed because I expected nothing along that line. But we'll get it some of these days. I will be interested when the reports come in as to the victories of the Yale expeditionary force over the allied Miocene troops. I expect they'll make a killing all right. I look forward to a good heart-to-heart talk with Sinclair when he gets back. Perhaps it will clear up some things about the situation that I don't understand. Of one thing I am sure, that you have done and are doing everything that's possible to maintain friendly relations, and I can trust to your judgment to do what is best."

The remainder of August the party worked the quarry, continuing to remove many Moropus bones from the pocket. On September 1st, the fossils were packed in 14 wood boxes for shipment to New York, Stein and Whitford then departing. The next day, Roberts and Montgomery hauled the fossils by wagon to Harrison, completing the trip in 7 hours. Thomson accompanied them, and left Harrison by train that afternoon. He reached New York on September 10th, and worked in the laboratory on the Moropus skeleton No. 10 (from 1913). On September 23rd, the 1914 collection reached the museum, and Thomson began work on chalicothere skull No. 12, spending the rest of the year on the chalicothere collection.

Mammals found in the Southwest Excavation during the 1914 season included Moropus and Menoceras. There is no record of other mammals discovered by Thomson's party. Their search for a complete skeleton of Dinohyus remained unfulfilled, and Osborn's desire to find one of these entelodonts would prompt their return to the quarry. Whether occasional isolated bones of other mammals were found during the work in the chalicothere pocket is unknown; if such bones were found, they went unrecognized. It is probable that with relatively untrained men such as Stein and Whitford, such bones were overlooked, if they were present.

Two photographs of the bone bed in the 1914 cut were taken by Thomson (American Museum Nos. 19515,19510), and show chalicothere bones mixed with rhinoceros material in the north tunnel (Fig. 3.58). The larger heavier bones appear to lie flat on the bedding surface, whereas smaller lighter elements seem to show more inclination from the horizontal. Conspicuous in Figure 3.58 is the skull of a male rhinoceros in unstable inclination, its horn bosses at the highest point, and the skull with dorsal surface up, inclined downward into the sediment. This skull could never come to rest in water on a flat sediment surface in this position. It was either worked into this inclined state by current scouring around the skull, or was originally deposited within a mass of sediment in this position. The fact that many light and easily removed bones such as ribs and vertebrae are present along with the skull in the deposit suggests that the latter alternative is most probable, since if currents worked the deposit and inclined the skull, many of the ribs and vertebrae would have been removed.

By the end of 1914, the American Museum had discovered most of the chalicothere sample that it was eventually to remove from the quarry. Most of the key specimens had been excavated and transported to New York. Once at the museum, it became apparent that large adults, small adults, and juveniles were represented. The possibility that this was indeed a small population of Moropus now had to be considered, and the Holland-Peterson belief that two species were present at Agate seemed less certain.

3.3.5. 1916 Excavation

The automobile brought new mobility to field prospecting in the west, and Matthew and Thomson were anxious to take advantage of this situation. The American Museum party prospected widely within Nebraska in 1916, exploring the Niobrara valley, the Loup, Dismal and Calamus drainages, and the North Platte river west of the town of North Platte. Later Cenozoic rocks produced almost no worthwhile fossils, despite Matthew's focus on the 'Pliocene' beds. The early summer ended as a disappointing failure to find important later Cenozoic faunas in the region.

Thomson had left New York on May 25th, and began prospecting about 40 miles northeast of Alliance, Nebraska, along the Niobrara valley. A. C. Whitford and George Stoll assisted Thomson, who next traveled with him to the Broadwater-Lisco region along the North Platte River south of Alliance, where only fragments of rhinoceros, proboscidean, and camel were found early in June. Returning to Alliance on June 6th, Thomson and his men continued to search the breaks of the Hay Springs - Rushville area for fossils, finding little of value. On June 15th, the party was joined by W. D. Matthew. After collecting a crushed mammoth skull, Matthew and Thomson on June 19th took a train from Alliance to the Seneca-Halsey area on the middle Loup River to prospect the region, but without success, returning to Alliance on June 24th. The next day Matthew and Thomson traveled south to the Platte River near Bridgeport and worked the exposures at Court House Rock. They continued east to Oshkosh, examining exposures south of the town, and then went farther east to Birdwood Creek north of Hershey and to loess beds near the town of North Platte, which was the easternmost point reached along the river. By July 3rd, the party reached Sidney in the southwestern panhandle of the state, and continued on to Alliance, where camp was broken for a move to Valentine on the Niobrara River to the east. Thomson arrived in Valentine on July 4th, working in the area until July 14th, but worthwhile fossil discoveries were infrequent.

On July 15th, Matthew and Thomson traveled to Agate, and inspected the quarry on Carnegie Hill on July 16th. The next day, the men prepared Harold Cook's homestead shack (East Agate) for camp residence, and began work at the quarry on July 18th.

The early work of the season was described by Matthew in a letter to Osborn on July 14th:

"We have looked into the exposures in [northcentral

> Nebraska] with very disappointing results. The fossiliferous beds are mostly grassed over, and they have been pretty thoroughly culled over by Professor Barbour's parties in previous years when they were better exposed.... There remains now only the Rosebud country [South Dakota] to look into, and unless that yields something, we will have to give up the Pliocene and Upper Miocene in this state -- except its western border [in southern Sioux County].
>
> "This result of our work is owing to a factor that I had not counted on, the succession of wet seasons that has grassed over all the sandhills and sandy exposures of the upper Tertiary and Pleistocene. It is a surprising change from the conditions of 1901-3 and 1905-8 as I recall them. I do not think we can do much with these horizons unless we find the formations in New Mexico, Texas and elsewhere better exposed.
>
> "Whitford and Stoll will go up into the Rosebud country and work westward, while Thomson and I are going direct to Agate to take up work in the big quarry, and get out the material for our [rhinoceros] skeletons, and watch out for Dinohyus. The others will join us there as soon as they are through at Rosebud and will prospect with the automobile from Agate as a base-camp, especially to the west and south, as far as Rawhide Buttes and the Platte. There is a good deal of Lower Miocene to be looked into, and we need more Parahippus and Oxydactylus especially.
>
> "Barbour's party is working near here, but the material they have secured thus far is worthless scrap, although naturally I have not told them so. Troxell we found at Springview [Nebraska] working in a quarry that has possibilities, although he has not yet obtained anything of especial value. Sinclair has been working the Pawnee Creek beds, with very poor luck. It does not seem to be a lucky year for Miocene-Pliocene collecting."

Matthew then described the plan of excavation at Agate to Osborn on July 17th:

> "We will go at the Diceratherium section already cleared off, with a view of getting associated material of [rhinoceros], and with the hope of coming across Dinohyus."

So the 1916 Agate excavation resulted from the failure of the American Museum party to locate productive 'Pliocene' deposits in Nebraska. The party fell back upon the Agate quarries for lack of more important sites to work. Matthew worked with Thomson in the quarry from July 18 to the end of the month, when he left for Lincoln. The men gradually uncovered the 'Diceratherium bed' located in sections 3-10. As work progressed, a large area was excavated wherein the bones were displayed in relief, resulting in the best surviving photographs of the Menoceras bone bed at the Southwest Excavation, taken by Thomson (American Museum Nos. 101780,101781, Figs. 3.59, 3.60). Bones are numerous but do not

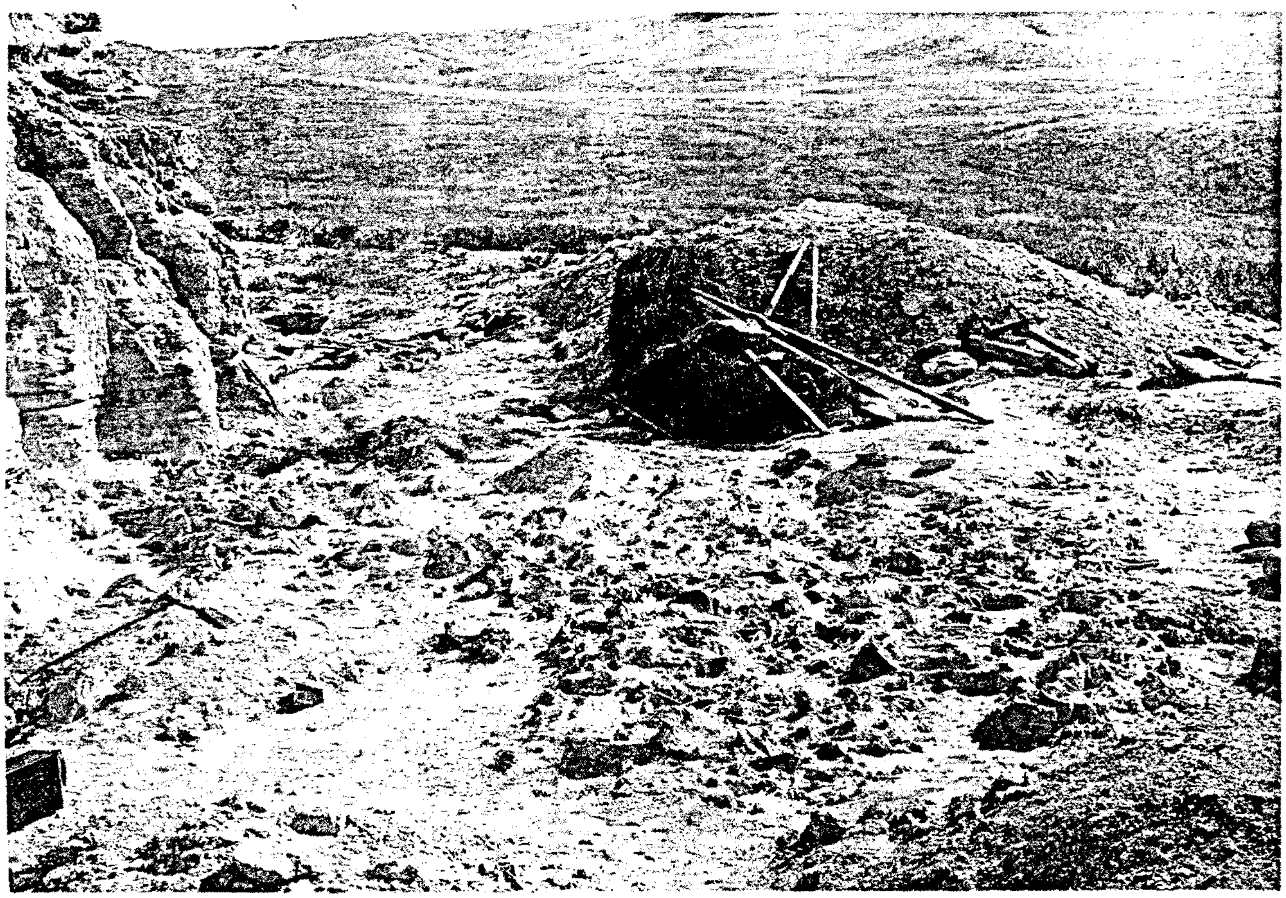


Fig. 3.59. In 1916, the American Museum party exposed a large part of the 'Diceratherium bed' in the Southwest Excavation on Carnegie Hill (Map G). This view of the bone bed from the north end of the quarry, looking south, shows numerous inclined bones, and is one of the few surviving photographs that documents the actual bone density in this part of the quarry (see also Fig. 3.60).

Fig. 3.60. The 1916 excavation of the 'Diceratherium bed' by the American Museum, looking southeast (see also Fig. 3.59). Note the large male Menoceras skull with prominent horn bosses in the left foreground.

seem to be as densely packed as some exhibit slabs that were taken from this part of the quarry. Many unstable inclinations are apparent, and at least two skulls are steeply tilted, with the tip of the nasals uppermost, the rear of the skull low. Bones are disarticulated; ribs, limb bones, skulls, jaws, vertebrae, and many smaller bones can be seen in the photographs.

In addition to rhinoceros, the party discovered additional chalicothere in 1916. Moropus No. 13 was found in section 10 at the west end of the 'Diceratherium bed', and included a skull, some limb and foot bones, pelvis and a few vertebrae. A second skeleton, Moropus No. 14 (AMNH 14423), was found in sections 7-8 immediately east of the 'Diceratherium bed', and included skull, jaws, pelvis, limb and foot bones, ribs, and a few vertebrae. The discovery of this skeleton occasioned the only extension of the quarry in 1916: Thomson blasted out a 5 foot deep alcove in the quarry wall to acquire the specimen (see Map F, sections 7-8).

The first chalicothere bones appeared on July 24th, and on August 10th a skull and lower jaws of a juvenile Dinohyus (AMNH 22730) was discovered in section 10 at the west end of the 'Diceratherium bed' (see Map G). This animal retained its milk premolars and an unworn adult first molar; it remains today the best juvenile entelodont skull and jaws found in the Agate quarries. With this discovery, the remains of 2 juvenile entelodonts (AMNH 22730, CM 2137,2137A) and 3 adults (CM 1594, AMNH 15866, 14442) had been found in the Southwest Excavation, but a relatively complete skull and skeleton continued to elude the American Museum workers.

By mid-August, Matthew had returned to New York, and reported to Osborn on his visits to museums on the return trip. Thomson was becoming increasingly dissatisfied with the work of Whitford and Stoll who had been quarrying in the Snake Creek beds about 20 miles south of Agate, and recommended to Matthew that they be discharged. Thomson intended to assume charge of the Snake Creek excavations in 1917, with the aim of improving the number and quality of fossil mammals from those quarries. As to the work in the Southwest Excavation, Thomson wrote on August 18th:

> "Now about the quarry work, we have uncovered a great deal more rhinoceros material back toward the bank where I dug the prospect hole. It seems to be dipping downward in the bank and that is a fair sign that there is something large inside. At least we have found it so before. Barner is a faithful worker and is worth more than the rest of my crew put together."

On August 21st, Thomson began to find Moropus running into the bank, and new chalicothere bones began to appear daily until August 26th when Thomson dynamited the bank to follow the Moropus bones. Debris from the blast was cleared, extending the cut 5 feet, and from August 28th until September 1st, Thomson records more chalicothere in the quarry. On September 6th, Whitford was fired by Matthew, who had written him to that effect, easing Thomson's problems in the field. Whitford and Stoll departed Agate on September 9th, their role in the work ended.

Early in September, Thomson mentioned in his diary that Harold Cook made a diagram of the quarry (Southwest Excavation). This diagram has not been found, and would be an important and interesting addition to the presently known maps of the Carnegie and American museums.

Work in the quarry continued into September, Thomson at one point writing, "No progress at all. Rhinos too thick." On September 17th, H. F. Osborn, accompanied by E. H. Barbour, arrived for an inspection of the quarries and an overview of the regional geology, now made possible by the advent of the automobile. Osborn made drawings and took notes on the quarry, and on the following day, toured the Snake Creek workings with Thomson, Barbour, and Harold Cook. During the next week, while Thomson and Barner excavated rhinoceroses in the quarry, Osborn, Barbour, and Cook explored the geology of the surrounding region, ranging from Scotts Bluff to Rawhide Creek. On September 25th, Osborn and Barbour left for the east, and Thomson finished the quarry work of 1916. The final days at the quarry in late September and early October produced only rhinoceros when the men badly wanted entelodont, and Thomson's diary is replete with many entries that read, "Nothing but rhino." Thomson wrote Matthew on September 26th, summarizing the work:

> "We have exposed all cleared space at the quarry and nothing but rhino has turned up. Prof. Osborn decided we should try and secure rhino material at the far end of the quarry where the bones are light colored, also try to get out a good block for exhibition. The bones are just as thick as ever and just as difficult to get out. So I am afraid we cannot do much this season.... I think I shall leave the stripping to be done on the north side of the hill to Barner after I leave."

This situation must have caused Thomson to place Barner at work on the north slope of Carnegie Hill at or near the old American Museum cut of 1907. On October 5th, Barner prospected the north side of the hill for the first time and found _Moropus_ material; he continued this for 5 days, leading Thomson to believe that the north slope of the hill might have future potential. For much of the remainder of October, Thomson and Barner prepared their fossils for shipment to New York, and aided Harold Cook with various projects. The quarry was closed on October 21st, and on October 26th, Thomson left Agate for Harrison, departing by train that evening.

In a final letter to Osborn on October 17th, Thomson revealed more details of the north slope excavation, and mentioned W. D.

Matthew's hypothesis on the origin of the deposit:

> "We did some prospecting on the northern slope of the bone hill and find Moropus and rhinoceros material running in, only not in such quantity as in the quarry. I think it would be wise to prospect it more thoroughly next season, as possibly it may be the edge of this great water or bog hole, and we may stand a better chance of getting a more or less complete rhinoceros skeleton."

3.3.6. <u>1917</u> <u>Excavation</u>

W. D. Matthew intended that Thomson and Barner work the Agate bone bed at Carnegie Hill in the summer of 1917. Exciting results emerged in the laboratory as a result of the preparation of the <u>Moropus</u> sample from the Southwest Excavation, and Matthew did not want to relinquish the quarries until the museum had achieved their aims. In March 1917, he wrote Harold Cook:

> "I know you will be pleased to hear of progress here, ... we have at last got the Moropus skeletons laid out and are sorting out the individuals. This is a considerable piece of work, as we find them more widely scattered than I had expected. But we have six or seven practically complete, and are rapidly building up others. There are clearly two sizes present in about equal numbers, and to our surprise we find that the large form has a broad pelvis, the small form a narrow one. This would seem to mean that the large form is the female, the small one the male....
>
> "Our expedition plans for the summer I think you know. We expect to have Barner and Thomson and young [Charles] Camp, who is Gregory's ablest student and has had some field experience, and I'll be with the party for about six weeks or so. We will work at the new cut in the Agate quarry, and open up the Snake Creek pockets systematically."

By June, the war had disrupted the planned field work, and Thomson remained in New York for the 1917 season. However, it was decided to send Charles Barner to Carnegie Hill to continue work on the north slope, begun the previous season. Because Thomson did not work at Agate, no field diary records each day's activity at the site, but letters between Harold Cook, Matthew, and Osborn provide a summary of work. On July 21st, Cook wrote Osborn:

> "Barner is hard at work, but to date has done principally stripping. Some splendid Moropus material is showing up where he is opening [the hill, as well as] some other things, [although] he has hardly exposed the bone bed well as yet. Dr. Figgins' party from Colorado is at work, and they are getting some fine rhino material out. They are finding some good Moropus foot parts near where your Moropus came from, and

I suggested to him that he turn this all over to you to see if any fits could be found with your skeletons."

Barner continued his excavation through the remainder of the summer, and into the fall of 1917. Matthew remained in New York, not entering the field work. On September 9th, Cook informed him further of the status of Barner's work and the excavation at Carnegie Hill by the Denver Museum:

> "[Dr. Figgins and his party] are closing work at the quarry now, and probably have actually left there by now. While they got no large Moropus material, they did get a lot of foot [bones].... As you are putting Moropus up, and many of these parts probably belong to animals you have there [in New York], it would be better to [send them to you by express]. They took out several large blocks, so it is apt to be some time before you get all of this material from them, as they will have to work these blocks up first."
>
> "Now while we are talking about Moropus, what do you want to do about the Moropus that Barner is finding in the new cut? I have told him to take out what he had to while prospecting; but I recall that Prof. Osborn said that he had all the Moropus you wanted, and so I told Barner to go slow on taking this up where not necessary, and to pack for storage what he did take up from the new cut .... Now that he has finished stripping on that side, he does not seem to be making much headway there, and does not seem to know what to do. You see, almost anywhere you start there, you find bone. Of course we do not want to destroy Moropus, or anything of special interest or value, and if the museum does not want it collected, I hardly know what to tell him to do, until I hear from you. There seems to be two bone layers there in one place, about three feet part, [although] I have not had time to see how extensive it is, and Barner seems to have little idea of it. Barner is willing enough, but he has a very small allowance of initiative, and cannot accomplish alone nearly what he would when with someone like Thomson."

It is evident that Barner was capable of little more than clearing the north slope of Carnegie Hill for later work by more skilled men like Thomson. Without its experienced men in the field, the museum would accomplish little of value at Agate. No photographs of the 1917 work were taken, since Thomson was not present, so we cannot know much of Barner's work, nor Cook's fascinating comment about two layers of bone on the north side of Carnegie Hill. On September 20th, Osborn wrote Cook, making clear the museum's remaining goal in the quarries:

> "I am interested to know whether Barner has come on any remains of <u>Dinohyus</u> in the new clearing. This is the animal we most need in the entire Tertiary Mammal Hall at the present time.

"The *Moropus* skeletons have turned out splendidly because they belong to separate individuals which have been pretty well sorted out. I hope we can secure some sales or exchanges and can make the beginnings of the Agate Quarry museum building; but these are bad times for paleontology as well as all other branches of science. All our finest young men are going into the war service."

On October 12th, Harold Cook in a letter to Osborn describes most fully the location of Barner's 1917 cut, and his results:

"Barner has closed and covered the quarry for the winter, and he found some very large Moropus there, and certain other small things. I did not have the time to see much of his work, and, as he covered things as fast as he got into the real bone layer, and took very little up, I do not know whether he found any real evidence of Dinohyus or not. Of course he would not know many of the bones if he saw them, to tell for sure what they were. But he did not recognize any good Dinohyus leads. The bone is abundant there, and as he has stripped the whole north face of the hill, it will not take much work now by someone like Thomson to determine just what the leads are."

Osborn was now anxious to sell or exchange the chalicothere skeletons from the American Museum *Moropus* quarry, but the war prevented any demand for these fossils. By July 1917, Osborn wrote James Cook his estimate of the number of chalicotheres in the sample: "You will be delighted to hear that we have at last rounded up the Moropus skeletons and that they prove to be far more complete and remarkable than we had dared hope for. There are no less than 17 skeletons ...." Although Matthew and Osborn decided to divide and distribute this superb population sample of these mammals, Osborn did have the foresight to photograph the individual skeletons as they were assembled by his staff from the blocks in the quarry. These photographs and measurement data gathered by Osborn in his unpublished manuscript on the Agate chalicothere sample give some idea of the material, but which specimens have a strong probability of association of bones, and which are less certain is not clarified. Thomson's field map of these chalicotheres thus is the best guide to these associations (Map H), and it is used in the taphonomic analysis of the Southwest Excavation.

Between the field seasons of 1917 and 1918, research on the American Museum chalicothere sample culminated in a draft manuscript by Osborn, part of it sent in February 1918 to Harold Cook for approval. Osborn observed in August 1918 that all the *Moropus* skeletons were worked out at that time, but "no one has any money at all; everyone is giving his last dollar to the war;... I see no future prospects whatever of sales abroad. The foreign institutions will all be desperately poor for years to come...."

Correspondence indicates that some Moropus must have been rather easily assembled into skeletons made up of bones of one individual, and that in the case of others, the bones were not clearly associated, so that composite skeletons were the result. Thus some Moropus, such as the University of Nebraska mount, are in fact composite skeletons, and not entirely derived from a single individual, as proven by a letter of May 3, 1918, from Matthew to Cook: "We have been delayed longer than I had expected in completing the Moropus skeleton for Professor Barbour, as it has been very tedious to sort out the best fits among the odds and ends, now that we have completed the individual fits."

3.3.7. 1918: Second Interlude

Thomson's purpose in 1918 was to work the Snake Creek beds in southern Sioux County. The American Museum did not excavate in the Agate quarries in 1918, but Thomson headquartered at 'East Agate', and took time to observe the work done by Charles Barner on the north slope of Carnegie Hill in 1917. Arriving at Agate on June 29th, and in need of rest, he spent the next weeks repairing the museum's Ford automobile, and looking over the Snake Creek deposits. He made a few brief visits to Carnegie Hill during July. On July 1st, he assessed the work of the 1917 season for the first time in his field diary: "Went down to the quarry to look things over. Barner left things in bad shape." Later, on July 24th, he wrote Matthew in more detail:

> "Things at the quarry are in fair shape - that is, the new cut where Barner worked last season. The wind and heavy rains have uncovered some of the material. There seems to be two bone layers there, and the bones are not as thick as they are in the old quarry. The bones are apparently in a better state of preservation."

By August 1st, Thomson felt ready to begin regular work in the Snake Creek beds, and described his routine to Osborn on August 9th:

> "As I am just in from my 'summer resort' on Snake Creek, I thought I would drop you a short note on my progress etc. I am alone so far, camping near my work, and coming back to Agate once and twice a week. I certainly would have been out of luck had I not repaired the old Ford. As yet I have not met with much success, but a great deal of sand shifting. The bones are not as plentiful as they should be and as you know very fragmentary."

Thomson cleaned and repaired Cook's shack at 'East Agate' in anticipation of the arrival of his wife, who joined him at Agate on August 10th. By mid-month, Thomson's attention to Carnegie Hill sites had been limited to prospecting the north slope of the hill on August 14th. During the remainder of the month, Thomson, assisted by his wife, continued work in the Snake Creek deposits. Nevertheless, in a letter to Osborn on September 4th, he gives more detail on Barner's cut at Carnegie Hill, and again mentions the enigmatic double bone layer:

> "Things at the old Bone Hill are about as they were two years ago when you saw it. The Denver Museum people last season took out quite a large block on the eastern end of what we had uncovered [probably the southeast end of the American Museum 'Diceratherium bed']. The new cut made by Mr. Barner on the northern slope of the hill last year is quite extensive, about 200 ft. long by 15 or 20 ft. wide. There seems to be two bone layers in this quarry as far as I can see. The bones are not quite as thick as they are in the old quarry [Southwest Excavation]. [Menoceras] is very much in evidence. Quite a number of Moropus bones showing. But Dinohyus is still in the bank out of sight. I am planning on doing a little searching for him when the weather no longer permits me working on Snake Creek. We worked a week in the Sinclair Draw quarries where the boys worked in 1916. We had planned on doing a great deal of work there, but for the gentleman [Ashbrook] who owns that whole section. He very kindly informed us he did not care to have us work there any more. I neither pleaded nor argued with the man, but moved back to the western exposures, and intend finishing the season there unless the owner of that property asks us to move out, in which case I will come here [Agate] and prospect either in the new cut on the Bone Hill or in the Stenomylus quarry."

A few days earlier, Thomson mentioned to Matthew the possibility of looking over the south side of Stenomylus Hill "in search of carnivore material which I know occurs there." It is possible this is in reference to the articulated skeleton of a large amphicyonid carnivore found on the south side of Stenomylus Hill by F. B. Loomis, which he had called Daphoenodon. This beardog, which eventually proved to be an unnamed temnocyonine amphicyonid, was photographed during its removal from Stenomylus Hill. When these photos are aligned with present day landmarks in the area, we find that this carnivore was found high on the south side of the hill. Perhaps Thomson was aware of this, and intended to try to find more carnivore material in the same place. This is of some importance, because the temnocyonine beardog found at Stenomylus Hill by Loomis is the same species as the temnocyonine found by our party in 1981 at Beardog Hill (Carnegie Quarry 3). Together, they are the only individuals of this species known at the present time.

On September 8th, Thomson did prospect Stenomylus Hill, but reported no unusual discoveries. He and his wife continued to work in the Snake Creek beds until mid-September, returning to Agate on September 24th. After packing fossils and preparing his camp equipment for storage, the Thomsons left Agate on September 27th, spending a month with Thomson's parents near Rapid City, South

Dakota, and returning to New York on October 25th.

On his last foray into the Snake Creek beds in September, Thomson could not start the museum's Ford for the return to Agate. This passage from his description of the incident reveals Thomson as the quintessential field man that he surely was:

> "Last Saturday night it began sleeting and raining and continued through the night and all day Sunday which made camping very unpleasant. I worked the greater part of Sunday forenoon getting the Ford started. Luckily, I had gathered a large quantity of 'cow-chips' and had them in a dry place. So I drew the water out of the Ford radiator, put it into our water can, and heated the water to boiling point, gave it to the Ford and began turning the crank -- a spark at last and we were off, all like drowned rats but happy to think we were on the way to the shack. That night a killing frost visited the whole country, so we spent yesterday drying ourselves and making preparations for another pull at Snake Creek today."

3.3.8. <u>1919 Excavation</u>

Thomson returned to active work in the Southwest Excavation at Carnegie Hill in 1919. The principal achievement of the field season was the removal of a huge exhibit block of rhinoceros bones from the 'Diceratherium bed' for display at the American Museum (Fig. 3.61). This block, which weighed over two tons, was excavated from the bone bed in the quarry floor, boxed, and transported by wagon and team to the railroad. The block measured 8.5 feet long by 4.5 feet wide (Fig. 3.62). It was one of Thomson's best efforts, and can be seen today in the Hall of Mammals at the American Museum in New York.

Accompanied by George Olsen, Thomson reached Agate on June 19th. During the next few days, they prepared their camp at 'East Agate' near the main hills, and prospected in the Southwest Excavation for their desired exhibition slab. On June 25th, they began work in the quarry on the bone bed. By July 10th, the block had been separated by a peripheral trench from the remainder of the rhinoceros-rich bone layer (Fig. 3.62). The surface of the block with its dense bone mass was coated with shellac dissolved in alcohol to harden it.

After completing the initial work on the rhino slab, Thomson and Olsen began work on the north side of Carnegie Hill in Barner's cut of 1917 (Fig. 3.63). On July 14th, they cleared and stripped the old cut. The north slope was worked from mid-July until July 23rd, when the men returned to plaster the large slab on the other side of Carnegie Hill. The job took three days. In mid-July, Thomson wrote Matthew of their progress:

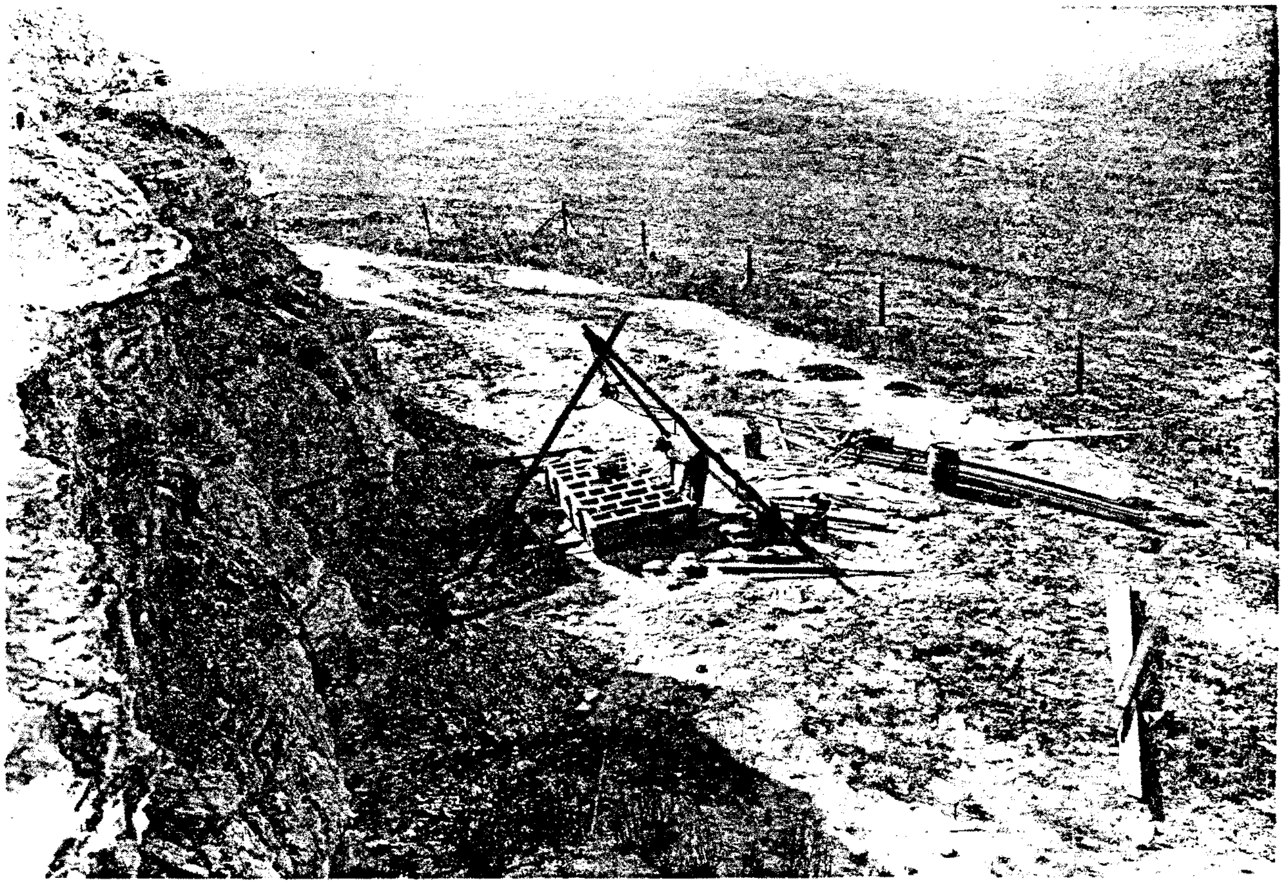


Fig. 3.61. Removal of the 1919 American Museum exhibition slab of Menoceras bones from the 'Diceratherium bed' in the Southwest Excavation, Carnegie Hill, looking south.

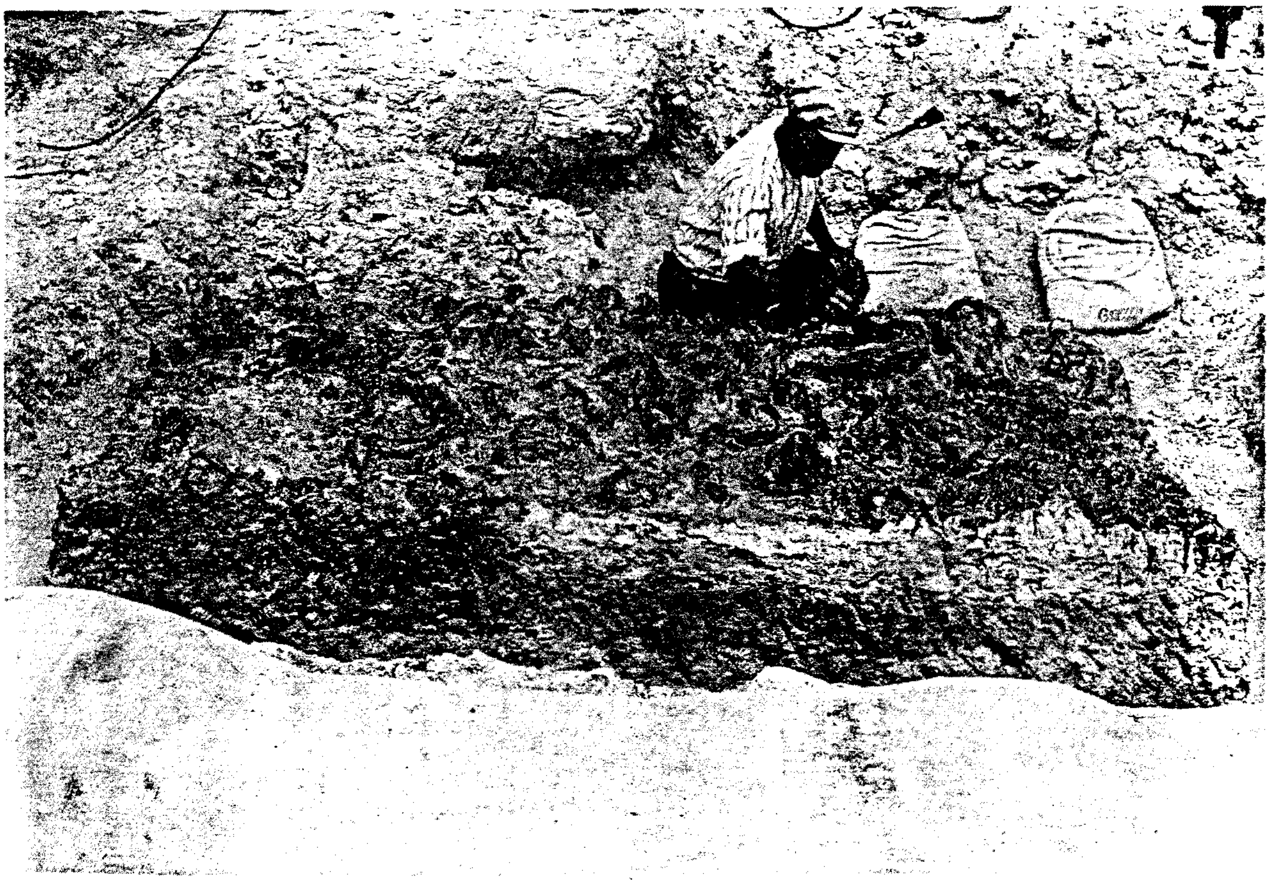


Fig. 3.62. Albert (Bill) Thomson of the American Museum at work on the 1919 rhinoceros slab at Carnegie Hill (see Fig. 3.61). The slab when crated for shipment weighed 4500 pounds, and was transported to New York on a railroad flat car.

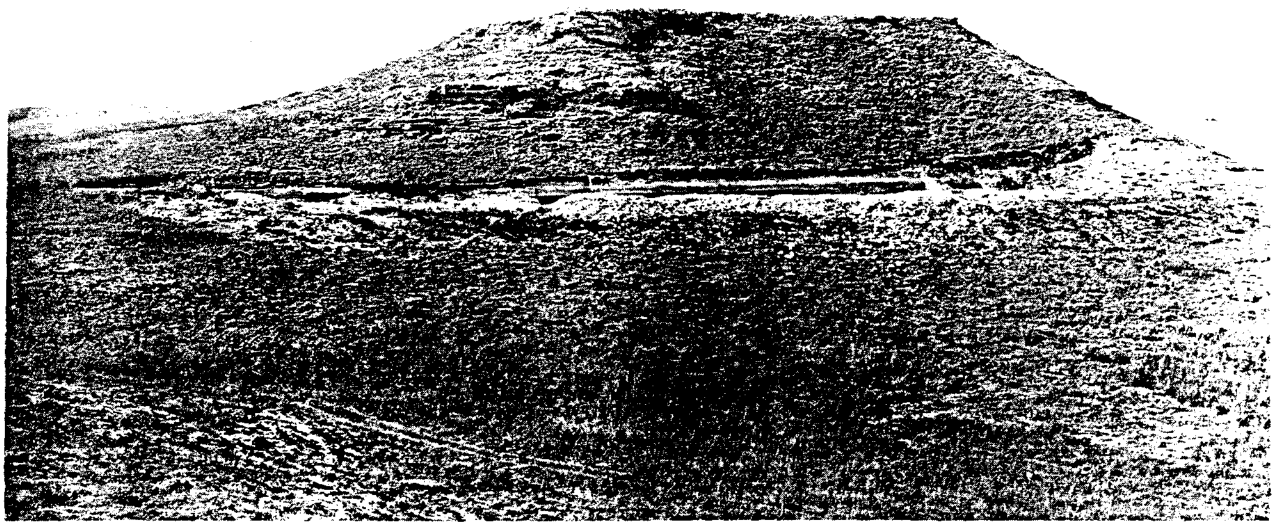


Fig. 3.63. The American Museum cut of 1919 on the north side of Carnegie Hill (see Map A, North Excavation). This large cut was superimposed on Charles Barner's earlier cut of 1917. Thomson and Barner both reported a double bone layer in the cut, and suggested that the bones were not as thick and densely packed as on the opposite side of the hill. The initial American Museum quarry of 1907 is at the extreme left end of the cut.

"We are making good progress in the quarry considering the beastly hot weather. It almost got the best of us. The thermometer up at Agate has been registering from 92 to 102 degrees in the shade among the trees, so just imagine what it must be at the quarry, even under the awning.

"We have blocked out a very handsome slab, 8 1/2 feet long, 4 1/2 feet wide and 15 inches deep. I think when it is ready for shipment, it will weigh about 4500 pounds. It will make a handsome thing for exhibition. To my mind far superior to any slab ever taken out of the quarry. I'll be on my nerves' edge until I see it safely on exhibit in the American Museum. I wish Professor Osborn could see it as it is blocked out in the quarry. Fifteen skulls in sight. It will take some time to get it securely bound and crated.

"We have prospected some in the quarry on the north side of the hill, and I think there is our only hope for Dinohyus. It seems to me that what Moropus bones I have seen there are somewhat larger than in our old quarry [in the Southwest Excavation]. This may be purely imagination, but if so, there is where Dinohyus should be.

"The other day we picked up a crocodile tooth while blocking out our slab. I also have a lower molar of some creature, which resembles both Moropus and Dinohyus, which I picked up in the north side quarry. Harold does not seem to know what it is."

Thomson's report of a crocodilian tooth is as significant as his later mention of the double bone layer found in the North Excavation at Carnegie Hill. Crocodilians serve as important environmental indicators, since they are restricted to climatic settings without prolonged and severe cold. We know of crocodilian fossils in the lower part of the Arikaree rocks in western Nebraska, and in the formations close above the quarry level, suggesting that the climate in the Early Miocene, while probably seasonal, did not include severe winters. But a crocodilian tooth from the quarry suggests that a body of water was not too distant from the site, and that the climate could accomodate these reptiles. This tooth has not survived in the American Museum collection to my knowledge, so until another is forthcoming, the record of Crocodilia at the bone bed should be considered provisional.

On July 26th, Olsen and Thomson continued their excavation of the north side of the hill. On August 5th, Thomson reported the discovery of Moropus jaws, ribs, ulna, radius, scapula and foot bones, thus possibly an associated forelimb. As work progressed, often the comments in Thomson's diary indicate little result for a day's labor. Bones could not have been as dense as many parts of the bone bed in the Southwest Excavation. On August 26th, after many days on the north slope, the men returned to work on the large slab. On September 4-5, the huge slab was cut from its pedestal, and prepared over the next week to be turned. Thomson developed a rigging to turn the slab over, which was completed successfully on

September 11th. The underside of the block was filled with cement, and the frame braced and bolted. By September 20th, the slab had been returned to its original position and a cover prepared. Since ceasing work on the north slope, the preparation of the slab had taken three weeks' hard and concentrated effort.

The remainder of the season at Agate saw the prosecution of various miscellaneous tasks by Olsen and Thomson, none involving a focused excavation in the main hills. On October 13th, at the end of the field season, the men closed the quarry on the north slope of Carnegie Hill. Fortunately, Thomson recorded his most important observations on the 1919 excavation at this site, placing these notes in his American Museum field book:

> "Nearly two months work was done this season on the north side of the Quarry Hill in search of Dinohyus. Only very few scattered foot bones secured. Moropus and [Menoceras] appear but mostly waterworn material and not in such abundance as on the southern side of the hill. The bottom of the north side quarry is very irregular. On the eastern end of this quarry, there are two distinct bone layers which come together in the west end of the quarry, not far from the old Utterback cut [Carnegie Qu. 2].
>
> "We made a cut about 180 feet long, and back 8 and 10 feet .... Further excavation must be done with team and scraper."

This passage by Thomson is the clearest description of the 'double bone layer' on the north slope, and indicates where one would dig to expose this for study. This is one of the most interesting and scientifically useful revelations to come from search of the older records. A double bone layer has significant implications for the origin of the bone bed on the north slope: when coupled with the irregular base to the bone bed (Fig. 3.64) reported by Thomson, and the waterworn condition of much of the material, there can be little doubt that the north side of the hill has been influenced by flowing water, and must be much like the deposit at University Hill. Both sites apparently differ from the dense bone bed of the Southwest Excavation. The implications of these findings are explored in section 2.5, a discussion of the origin of the Agate bone bed.

The quarry slab was taken by vehicle to Harrison, where in mid-October it was loaded on a railroad flat car for transport to New York. The job was finished none too soon, as the following day Thomson was snowed in at Harrison. Olsen and Thomson returned the next day to Agate, closed their camp, and departed the quarry hills on October 27th, reaching New York in mid-November.

The field work of 1919 was significant, not because of the bone slab removed to New York, but because of Thomson's observations on the North Excavation at Carnegie Hill. We find out not only about

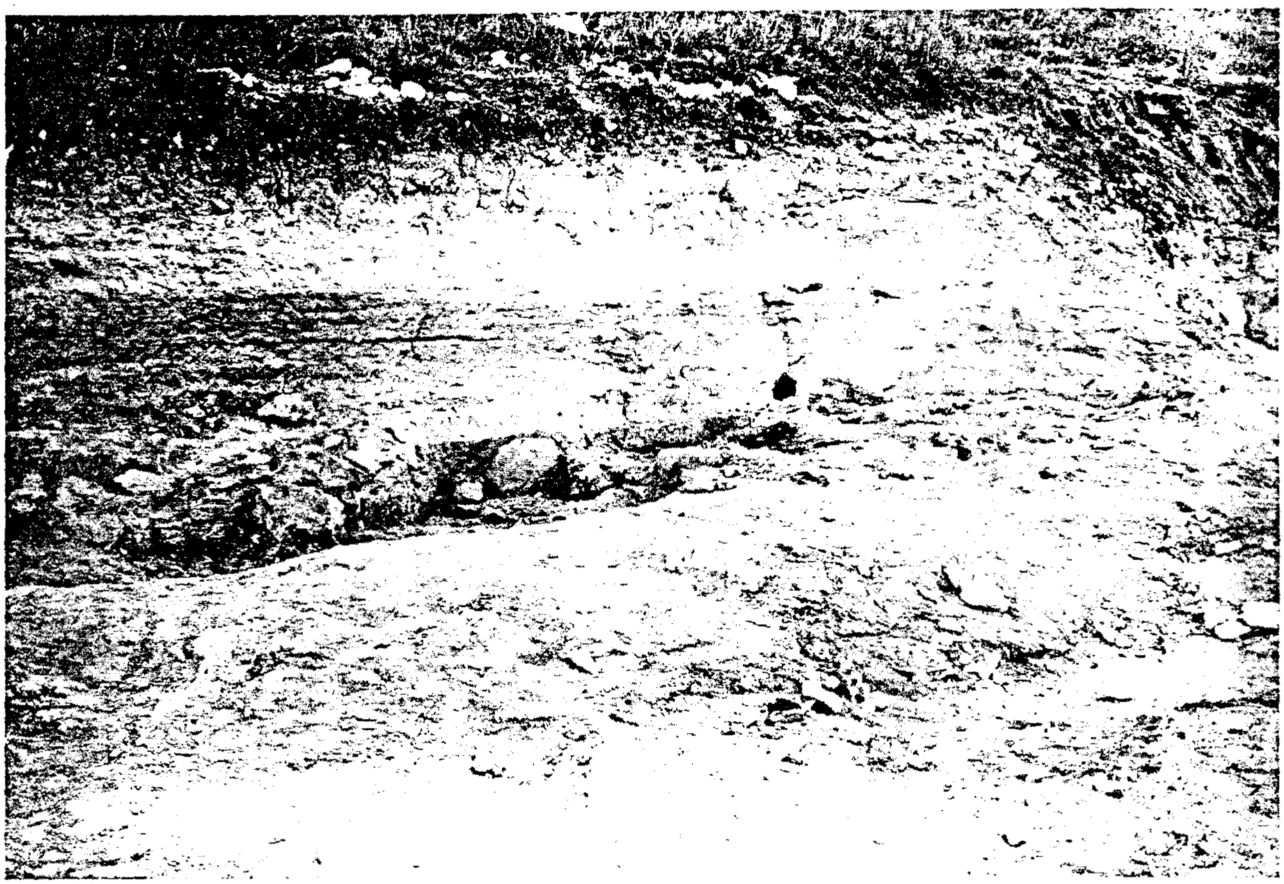


Fig. 3.64. Thomson's field photograph of the irregular bottom of the bone bed on the north side of Carnegie Hill (North Excavation, Map A) as exposed in 1919.

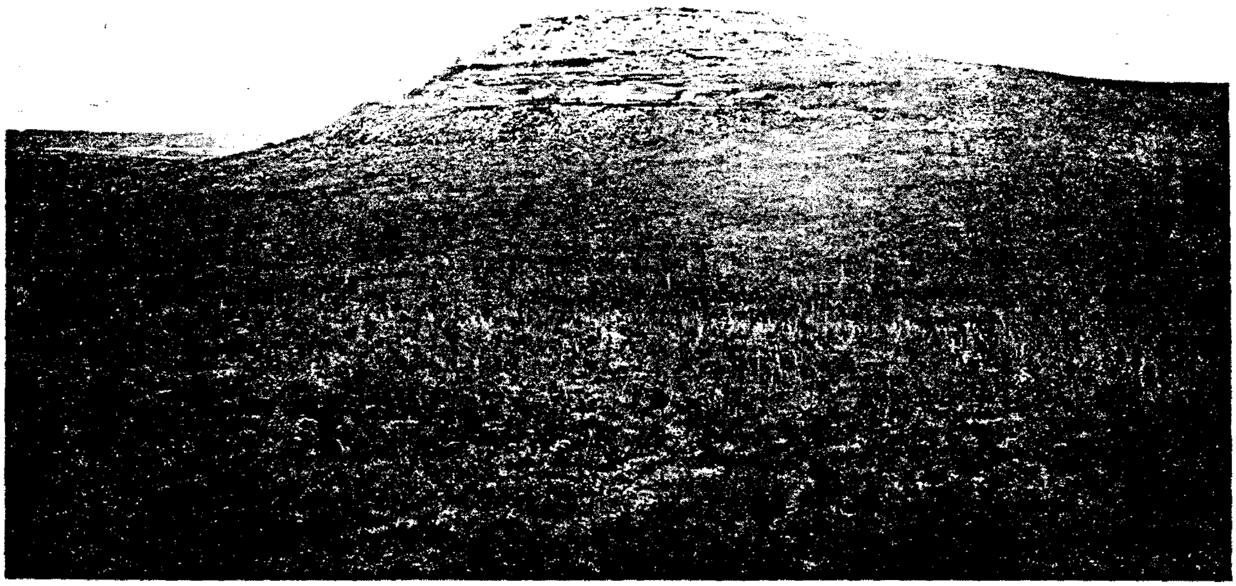


Fig. 3.65. Southwest Excavation on Carnegie Hill, showing the length of the quarry in 1920, following the development of a north extension by Thomson and Olsen of the American Museum in their search for a complete entelodont skeleton. It is at this time that the Southwest Excavation reached its present dimensions. See Figures 3.66 to 3.68.

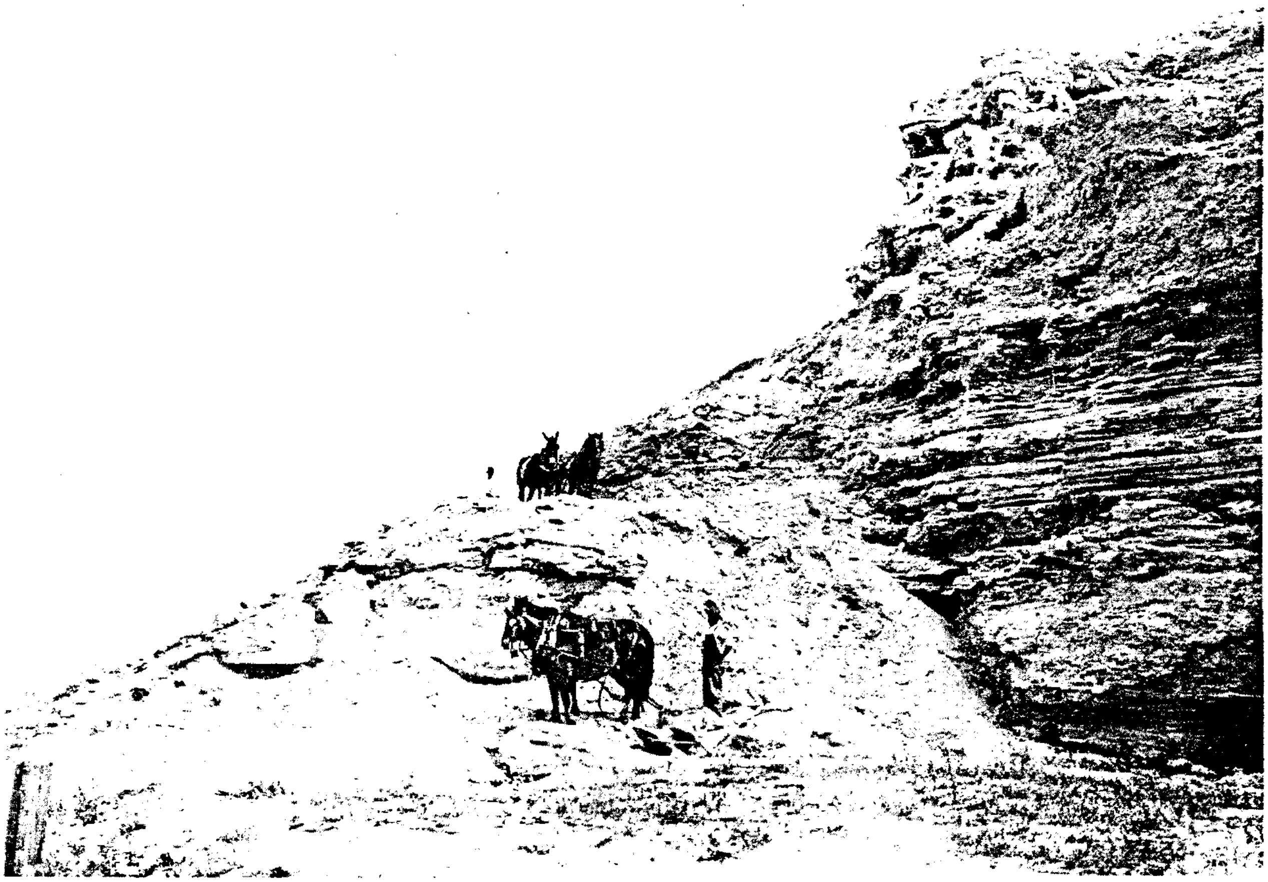


Fig. 3.66. Teams and scrapers at work in 1920 in the north end of the Southwest Excavation, during the development of a northern extension to the quarry by the American Museum party. The extension, once excavated, produced more chalicothere bones mixed with some rhinoceros material.

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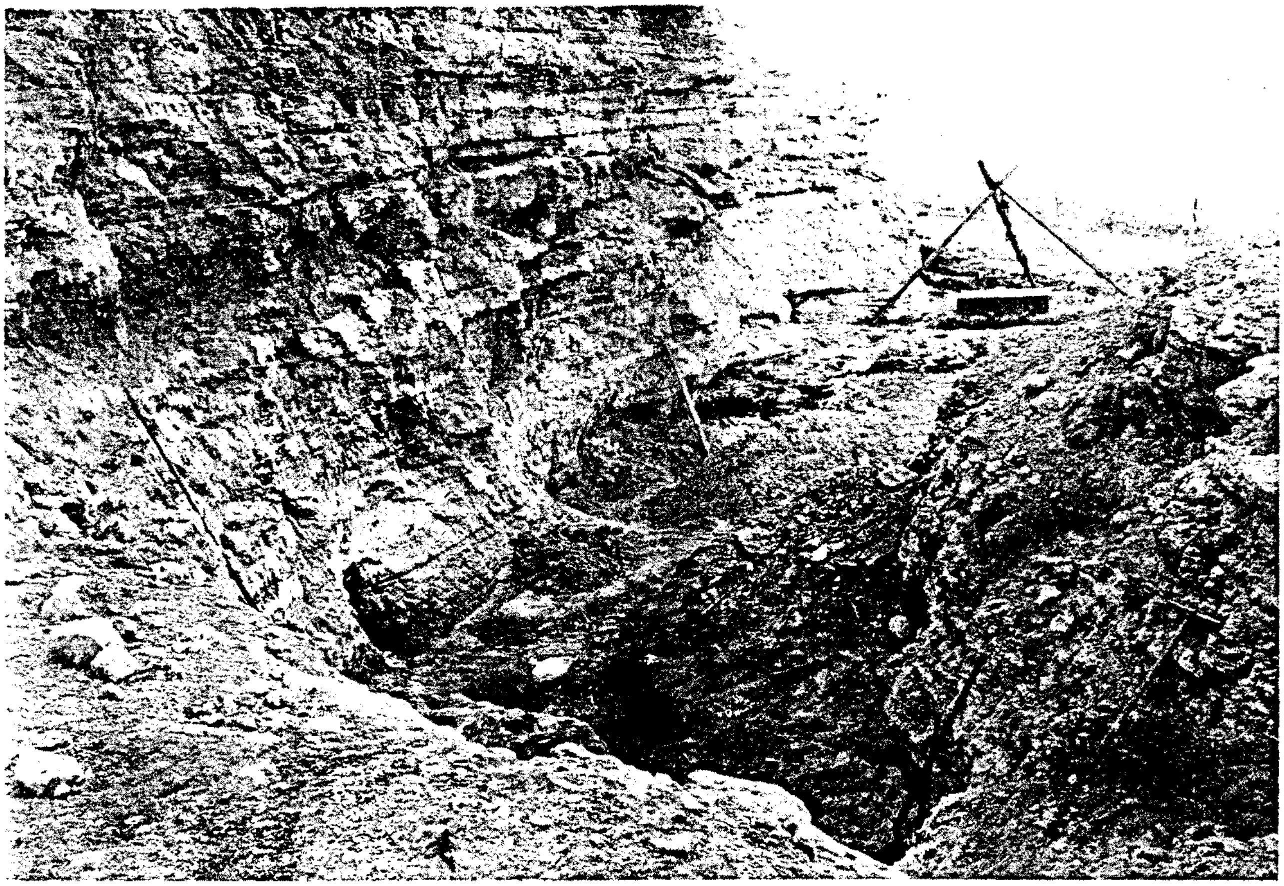

Fig. 3.67. Looking south along the new 1920 cut (Map F) that produced bones of chalicothere and rhinoceros at the north end of the Southwest Excavation, Carnegie Hill. A channel margin was intersected on the right side of the photograph, according to Thomson's notes. Fossil bone occurs over a considerable vertical distance in the new cut. Slab in distance has been excavated by Paul Miller of the University of Chicago from the 'Diceratherium bed' in 1920.

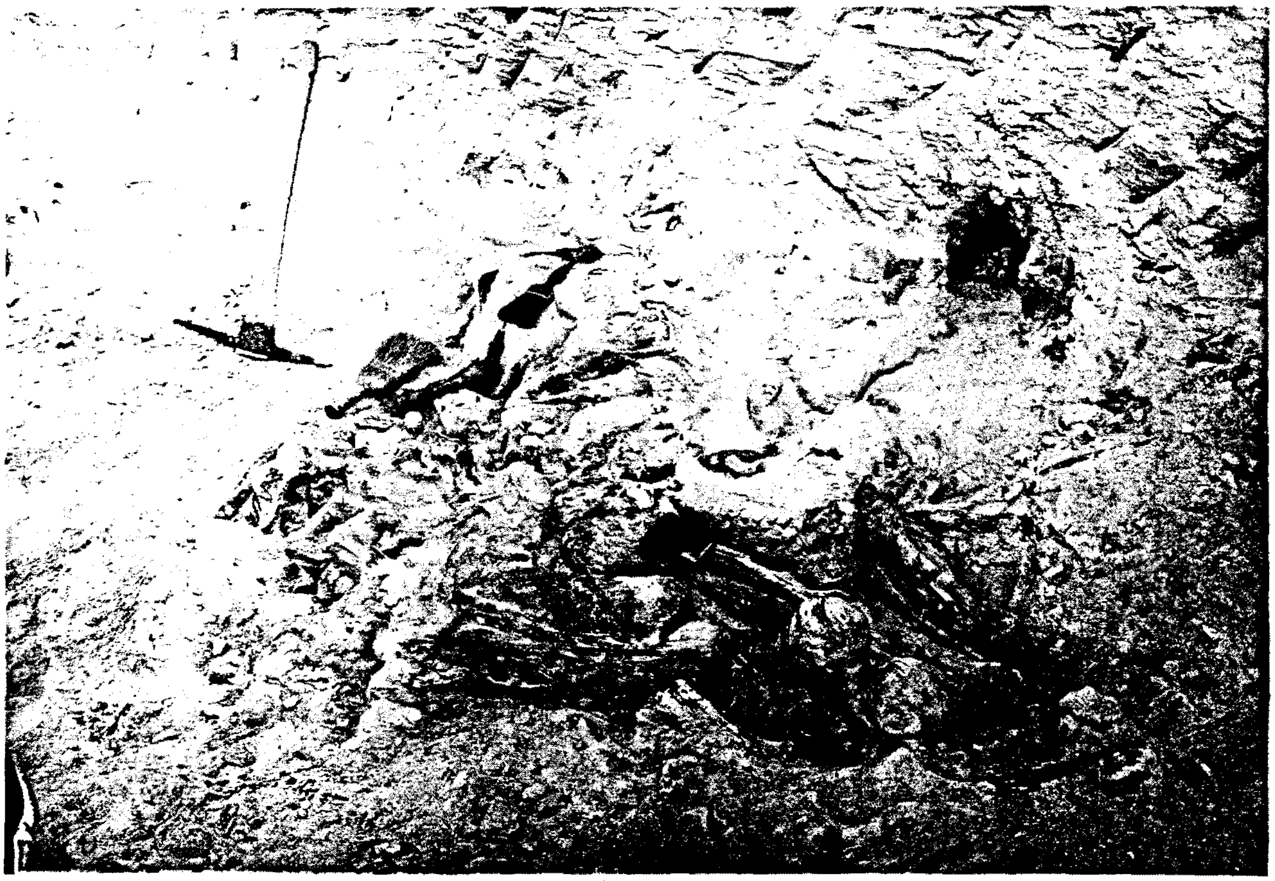

Fig. 3.68. Moropus bones mixed with remains of rhinoceros on the floor of the 1920 cut, north end of Southwest Excavation, Carnegie Hill. A very large male chalicothere was discovered in the cut by Thomson and his men.

the dual bone layer, but also that the quarry contained chalicothere (including a possibly associated foreleg), the small rhino Menoceras, and scattered entelodont bones, thus the common mammals of the other Agate sites are present here as well. The fossils from the 1919 work have been incorporated in the American Museum Agate collection, but the sample has not been segregated from other Agate specimens.

3.3.9. 1920 Excavation

Frustrated by their failure to find a skeleton of the entelodont Dinohyus, the American Museum party returned to Agate in 1920 for their last major effort in the Southwest Excavation at Carnegie Hill. Bill Thomson, his wife, and George Olsen, assisted by several local men, undertook a long season's work extending from June through November. As his principal aim, Thomson extended the Southwest Excavation to the north, making a new cut of considerable size (Fig. 3.65), in the hope of coming across a complete entelodont, but the actual fruits of the new extension turned out to be more chalicothere. The party did not carry out any work on the north slope of Carnegie Hill this year.

Thomson reached Agate on June 16th, headquartered at 'East Agate', and began preliminary work in the quarry on June 22nd. The remainder of June and all of July were devoted to drilling, blasting, and clearing the rock overburden from the new cut. Local men were employed with teams and scrapers (Fig. 3.66) to cut the outcrop down to the bone bed once the overlying rock was dynamited. From the time expended, one can see that this was a major undertaking, accomplished entirely through Thomson's experience and skill. Matthew brought Thomson's abilities to Osborn's attention, for Thomson dearly wished to improve his field equipment, adding a new field vehicle if possible. But recognition in terms of concrete rewards was slow in coming. And this, despite a field effort carried on six days each week, in all weather, with patience, skill, and often consummate tact and diplomacy. To W. D. Matthew in early July, Thomson described the state of the art:

> "Just a short note to let you know how we are progressing with our work at the quarry. Very slowly just at present owing to difficulty in getting blasting powder and dynamite, but hope to get a good supply in a few days. We were fortunate enough to have an old keg of powder on hand so we have been using it carefully, and breaking ourselves in on the 'man killer'(the big pick).
>
> "The corner we are cutting away is twenty odd feet from top down to bone layer and very concretionary. It may take us some time, but if we do not find a Dinohyus, we are sure to find Moropus material belonging with some of our skeletons. I am afraid we will have all we can do in the quarry without attempting to do any other work this season.... Our old Ford

is still able to travel a little but can't be depended upon for a long trip. The day I went over to Andrews to meet Mrs. Thomson I thought I'd never get there, and coming back, a rear wheel came off. But a wire nail and part of an old spark plug -- along with some real english -- patched the thing up and we came on to camp ...."

Use of team and scraper ended on August 2nd, for the bone bed was coming into view after over one month's labor. On August 3rd, Thomson wrote in his field diary: "At the quarry all day prospecting but not quite onto the bones. Moropus in edge of quarry where we left off in 1916."

Prospecting of the bone bed continued from early August until August 17th (Fig. 3.67). By the end of the first week, chalicothere bones were appearing at a steady rate, and on August 23rd a very fine Moropus skull was discovered. By the end of August, Thomson recorded both Menoceras (including a number of skulls) and Moropus from the new quarry extension (Fig. 3.68).

Some bones were closely associated in the quarry. In mid-September, a particularly rich Moropus bone concentration was discovered, and at the beginning of the second week in October, a very large Moropus began to appear in the bone bed -- association is indicated because of Thomson's remark that "another set of foot bones appeared." [underline - RMH] In addition, a photograph by Thomson shows close association of femora and tibia of the large chalicothere (Fig. 3.68).

The best summary of the 1920 work was written by Thomson in his American Museum field book:

> "Began excavating at the northwest end of the old quarry where work was left off in 1914. A cut about 100 ft. by 20 ft. was begun and worked down about 15 ft., then the cut was cut in half down to bone layer which was about 15 ft. more. At the bone layer we came in contact with the original channel bed bank which cut off about half of our expected uncovering. Though just in beyond this bank a very good pocket occurred. Rhinoceros material principally, though a great deal of Moropus as well, which undoubtedly belongs to skeletons already collected in 1914. No signs of Dinohyus material all season, but if any more occur in the hill, there is reason to believe it should be found in this pocket, if we keep working in, though from now on we must do tunneling."

Thus the 1920 collection included both rhinoceros and chalicothere, although Thomson reported that some rhinoceros bones were destroyed while taking out chalicothere material. At least 3 rhinoceros skulls were found in the new cut, probably many more. Thirteen large boxes of fossils from this work were shipped to the American Museum. Whether other mammals were found in the new cut, represented by rare isolated bones, is not known.

The only other record of work in the Agate quarries in 1920 includes Thomson's diary entry of October 15th, late in the season, reading: "Prof. Barbour came down and worked on his Rhino. slab covering it up." Whether such a slab ever was removed from the quarries is doubtful, since we have no record of this slab in the University of Nebraska collection. Correspondence also notes that Paul Miller removed a rhinoceros slab from the Southwest Excavation in 1920 for the University of Chicago, with the approval of the Cook family and the American Museum. This slab was taken from the Diceratherium bed (Fig. 3. 67).

On October 27th, Thomson and Olsen covered the bone layer in the new cut, and closed the quarry. Thomson and wife left Agate on November 4th, essentially ending the decade-long American Museum effort at Carnegie Hill in the Southwest Excavation. The last of the great Moropus sample had been taken from the quarry, perhaps leaving behind many of these unusual mammals for later generations, buried under tons of rock at the center of Carnegie Hill.

It is remarkable that so little information on the topography of the quarry floor was recorded in Thomson's field diaries and notebook during these years of work on Carnegie Hill's Southwest Excavation. The thickness of the bone bed, and the density and distribution of bones in different areas of the quarry are poorly known, despite several photographs of the bone bed. Of particular interest is Thomson's note of the existence of a preserved channel margin at the north end of the quarry. Information as to the alignment and steepness of this margin would be of much value in the interpretation of the deposit.

3.3.10. 1921 - 1922: Focus on Snake Creek

No excavations in the Agate quarries were carried out in 1921-22 by the American Museum. Realizing the potential of the Snake Creek district some 20 miles to the south of Agate, Matthew and Thomson devoted their field efforts to these beds.

In 1921, Thomson worked the Snake Creek quarries from late June through early October. About this time, two of the Moropus skeletons from the American Museum chalicothere quarry were sold to Harvard University, thus the division of the sample had begun.

In 1922, Thomson reached Agate on June 7th, worked chiefly in the Snake Creek deposits, and departed the field in mid-November, even for him a long season. However, in 1922 Thomson prospected the Agate hills from time to time, once in the company of James Cook, and later in an attempt to find carnivore fossils. Finally, at the end of the field season in October, he became interested in bones emerging from the bone bed at the south margin of Carnegie Hill: he wrote in his field diary on October 10th, "Found new lead to the Agate Spg Qu. about 40 yds. to the east. Many Moropus bones near surface." He explained more fully in his final field report of 1922:

> "We also opened a new prospect about fifty yards to the east of the old Agate Spring Quarry, which looks very promising. We found the same material as in the main quarry but the bones are not as thickly deposited, the matrix being harder. At present this would be much easier to work than the old quarry [i.e., the Southwest Excavation], because there is not so much surface to remove. The bones, being light in color, are beautiful and would make fine exhibition material. I am reasonably sure that a composite [*Menoceras*] skeleton can be secured. There is also a chance for *Dinohyus* and additional *Moropus* material. I think this new prospect would be well worth a season's work."

This site became the South Excavation or American Museum Quarry of 1923.

Additional evidence of other field parties at Agate in 1922 appears in a letter from Matthew to H. F. Osborn on July 16th, noting that Handel Martin of Kansas University had arrived at Agate, with the aim of obtaining a small block from the Agate bone bed. Because he had previously belonged to the American Museum staff, and because Martin had "worked hard under great difficulties to keep palaeontology alive at Kansas University," Matthew aided him with assistance and advice. Although there is no record of its site of origin, this block probably was taken from the American Museum's 'Diceratherium bed' in the Southwest Excavation.

Also, in 1922, Buettner and Hussey of the University of Michigan excavated in the Diceratherium bed of the Southwest Excavation, taking a small slab of *Menoceras* bones, presently on exhibit in the Museum of Paleontology at Ann Arbor. In this case, a photograph taken during removal of the slab indicates its exact position in the quarry.

3.3.11. 1923 Excavation

This field season marked the final major excavation by the American Museum at the Agate hills. In 1923, Thomson opened the South Excavation on Carnegie Hill (Fig. 3.69), but because of only average results after a few weeks' effort, abandoned the site. On June 15th, Thomson began the season's work in the Snake Creek district south of Agate in Sioux County. Thomson's party included his wife, Carl Sorenson and his wife, and for various amounts of time, Glenn Jepsen, Ray Lemley, Paul Miller, and occasional assistants. The Snake Creek - Sheep Creek quarries were worked steadily with moderate results from mid-June until August 4th. On

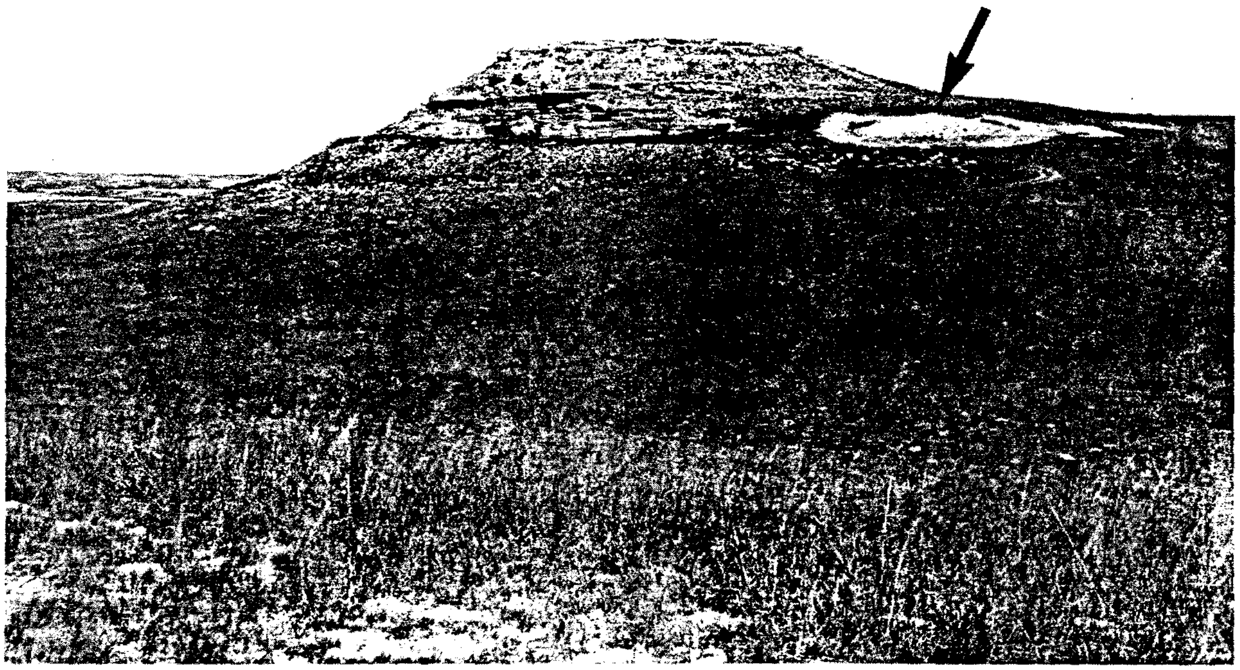

Fig. 3.69. The American Museum Quarry of 1923 (South Excavation, Map A) was the last major quarry (arrow) placed by this institution in the Agate hills, and marks the end of Albert Thomson's field effort at Agate.

the last day of July, Matthew advised Thomson that the time had come to move on:

"You seem to have done pretty well in the Snake Creek-Sheep Creek quarries.... I think you are wise to take up scouting work now, especially if you can get Paul [Miller] with you. We can always go back to the Upper Snake Creek for another try, and probably will from time to time, but we very much need other localities and associated material. The Snake Creek-Sheep Creek fauna is a pretty impressive one when you get it all together -- about 110 species in all -- but I think two months' prospecting in the Scotts Bluff - Goshen Hole country would show up a lot of promising localities that would pay to work intensively.... If, however, you find it necessary on account of Mrs. Thomson's health to stay on at Snake Creek or Agate, or keep a base camp there and return frequently to it, there is a good deal of prospecting for extensions of the Snake Creek deposits that would be practicable with your car."

By August 7th, Thomson had moved to the American Museum camp at 'East Agate', and explored a new site about 120 yards north of the "old Amherst Hill Quarry". F. B. Loomis had earlier located Stenomylus Quarry at Amherst Hill in 1907. About six Stenomylus skeletons were removed from the new quarry in 1923 by Thomson and Miller, but only minor excavation was undertaken.

Then, on August 15th, Thomson and Miller opened the South Excavation on Carnegie Hill (Figs. 3.70, 3.71). Thomson described the new site to Matthew in a letter from the field on August 19th:

"We have opened the old Agate Spring Quarry again where I made a new opening last fall. Paul [Miller] agreed with me that there is a good chance for Dinohyus in this new cut, and while there is so little stripping it would seem a pity to let it go and then have someone else find a Dinohyus with so little work right under our nose. From what we have already seen in this new prospect, there must be some good material, as there are so many Moropus bones, and signs of Dinohyus. We got a complete metapodial of a horse and a small carnivore (mustelid?) jaw there yesterday. Last week was the first week in some time that we did not have to dodge heavy showers. Owing to Mrs. Thomson's condition, I've not quite dared to go on my prospecting trip, though I am still hoping to find it possible to do so. Paul is still with us and I am certainly glad to have him. Collecting with a bunch of raw material is not what it is cracked up to be, though the boys and Carl are very good workers and fine fellows, the most agreeable set of boys ever in a bone camp. But a real Bone Digger cannot be turned out in one season's work."

Thomson gave a more complete report in his field notes of 1923 in the American Museum:

> "[On] August 15th we opened the Agate Spring Quarry to the southeast of the old cut [the Southwest Excavation] but where the stripping was not as heavy as the old cut. We had hopes of securing a Dinohyus skeleton but after two weeks of very hard labor, we gave up. However, we did find more signs of Dinohyus in this cut than at any time before.
>
> "On September 1st, Carl Sorenson and I were left alone. The boys we had employed began work on a Diceratherium slab for their colleges. Sorenson and I then set to prospecting the Upper Harrison beds....
>
> "Two Moropus femora were all we saved from the new cut."

Additional detail is provided in Thomson's later letters on the Agate site. Thomson writes on Sept. 8th:

> "We put in some time at the quarry but did not find Dinohyus, though we found a few foot bones and teeth of him -- that is more sign of him than we have seen in some time. The bones at that end of the quarry are not very thick, but nice and white. The matrix is hard but chips very readily. We could get only two days scraping done which did not let us in very far."

And on Sept. 23rd:

> "Our luck out here has been anything but good. I can almost carry our summer's collection in my suitcase."

The season's collection weighed 1500 pounds, and filled eleven large boxes, but how much of this was taken from the South Excavation of 1923 we do not know. The above-cited correspondence would leave the impression that only two chalicothere femora and a few miscellaneous other bones were saved. On October 1st, Thomson and Sorenson left Agate, ending the prolonged period of work at Carnegie Hill by the American Museum crews under Thomson's direction.

Mammals found in the South Excavation include chalicothere, entelodont, horse, and carnivore. Some Menoceras bones were also collected but are not specifically mentioned by Thomson. The fact that Thomson reported the bone bed to be less dense than the Southwest Excavation is an important observation: it suggests that the dense and thick bone concentration found in the Southwest Excavation may be confined to a limited area of the hill, bracketed between the thinner, less dense bone beds of the North and South Excavations. It is a hint that the Carnegie Hill bone bed possibly has a decipherable geometry which could tell us something of its origin.

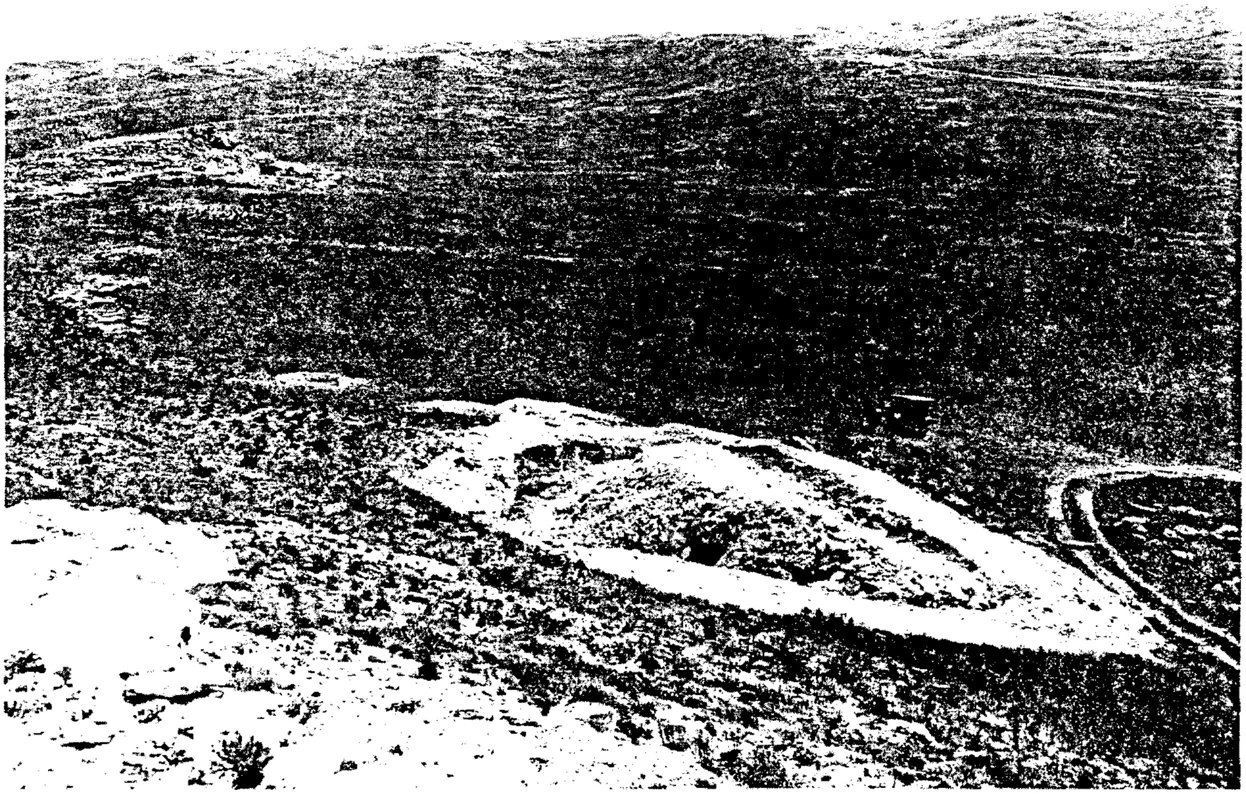

Fig. 3.70. Looking south over the American Museum Quarry of 1923 from the top of Carnegie Hill. Beardog Hill appears to the left; Carnegie Quarry 3 can be seen on the west (right) side of the hill.

Fig. 3.71. American Museum party at work in 1923 in the South Excavation, looking northwest, with Carnegie Hill in the right background. The large dump pile is still evident today at the site. Fossils reported by Albert Thomson from this site were more scattered and not as thickly deposited as in the nearby Southwest Excavation, and the quarry was soon abandoned.

<u>Abundance of Fossils in the Agate Hills: Matthew's Estimate of 1923</u>

The year 1923 marks a watershed in the Agate story. Conclusion of the American Museum excavations signaled the end of the period of intense interest in the Agate hills; later work would be occasional and often on a much smaller scale. Very often, such efforts involved the collection of small rhinoceros slabs by museums and universities in need of interesting exhibit material. In the same year, W. D. Matthew published a brief summary of the Agate work, in Natural History magazine, titled "Fossil Bones in the Rock". Here he presented in popular terms his theory on the formation of the Agate bone bed:

> "The bones are in a layer from six to twenty inches thick, packed closely together. They are seldom articulated, but most of the bones of a single skeleton lie near together, although some parts may be found at a little distance.... The formation is a rather soft sandstone of light gray color, made by the accumulated floodplain sediments of a river that flowed eastward across the plains, for then as now the region was one of open country and grassy savannas. It is believed that the accumulation of bones was formed in an eddy in the old river channel at a time when the valley was not so deeply cut out as it is now and when the river flowed at the higher level. A pool would be formed at this eddy, with quicksands at its bottom, and many of the animals that came to drink at the pool in dry seasons would be trapped and buried by the quicksand. The covering of sand would serve to protect the bones from decay and prevent them from being rolled or waterworn by the current, or from being crushed and broken up by the trampling of animals that came there to drink. But sand of this kind is always moving and shifting (whence its name of quick) and with it the buried bones would be shifted around, disarticulated, and displaced, so that when finally buried deeper by later sediments of the river valley, they would be preserved as they are found here, complete and almost undamaged, yet all separate and dissociated."

This is the clearest and most straight-forward statement of Matthew's quicksand theory. To it, Matthew appended an estimate of the number of mammals that he believed could be censused in the Agate deposit at Carnegie Hill: in number of individuals, he calculated 100 <u>Dinohyus</u>, 500 <u>Moropus</u>, and incredibly, 16,400 <u>Menoceras</u>. He arrived at this estimate in a most interesting way. First, he calculated the number of bones in an adult <u>Menoceras</u> skeleton (about 200). He next estimated the density of bones per square foot in the American Museum exhibit block of 1919: (1) the exhibit block contained, according to Matthew, 22 skulls; (2) he assumed that a full skeletal complement of bones accompanied each skull in the block, thus 22 skulls multiplied by about 200 bones =

about 4400 bones in a block having 44 square feet, thus 100 bones/sq. ft. However, this value was believed by Matthew to be too high, so he adopted an arbitrary value of 40 bones/sq. ft. for the 4100 square feet assigned by him to the Southwest Excavation (including both the Carnegie and American Museum quarries). His final estimate of 820 Menoceras skeletons was arrived at by multiplying 4100 square feet by 40 bones/sq. ft. to yield a value of 164,000 bones.

This estimate is probably close enough to the truth to be taken seriously. Although there are parts of the bone bed in the Southwest Excavation that are of very low bone density, or even barren, there are surely several hundred rhinoceros represented in the excavation, based on a count of only skulls. Our preliminary study indicates that the Southwest Excavation produced the highest bone densities in the main hills, thus these estimates are at the upper limit that should be expected in the deposit.

Matthew, however, errs in his extrapolation of the estimate derived from the Southwest Excavation to all of Carnegie Hill. To arrive at the total number of small rhinoceros in the Carnegie Hill bone bed, Matthew embraced Thomson's estimate that only 5% of the bone bed in the hill had been excavated. Accordingly, he multiplied his initial 820 rhinos by 20 and arrived at his final population estimate of 16,400, which he regarded as still probably too low.

This number of rhinoceroses would indeed be a staggering value, for it would approach the annual standing population of some East African antelope in the Serengeti ecosystem (Schaller, 1973). Population estimates in the Serengeti ecological unit in 1969 for kongoni, topi, zebra, and wildebeest were 18,000, 25,000, 150,000, and 500,000. If Matthew's estimate is accurate, then it would be evident that such an accumulation of individuals could not have died at one time, but would have to represent a gradual buildup over time. Reports of mass deaths in East African plains settings during the annual migration of the most abundant antelope (wildebeest) are on the order of at most several hundred individuals, and usually in the tens for a single event. For plains ungulates with smaller population sizes, the number would be much less. So it is important to evaluate the correctness of Matthew's estimate.

First, we know from the foregoing field records that the bone density in the Southwest Excavation is probably greater than in all quarries on Carnegie and University Hill. There is not much doubt that bone density in the Northwest Excavation was lower, and it is certainly true in the North Excavation and at University Quarry. The actual bone density must be measured by field quadrats in reopened sites on the hills, but in the interim, we can estimate that bone densities in the quarries were similar to University Quarry where blocks collected for exhibit only attain a maximum value of 25 bones/sq.ft., and average 15 to 17 bones/sq.ft. However, to use these values of from 15 to 25 bones/sq.ft. over the entire quarry floor would be erroneous because some areas of the floor of University Quarry are barren. Let us analyze the floor of University Quarry to estimate the average bone density of such an excavation.

Bone density at University Quarry can be estimated by reconstructing the pattern of bone distribution on the quarry floor from field maps of the site made by E. H. Barbour during the 1906 and 1908 excavations. We can derive several useful items of information from a study of this map that help in any estimation of overall bone density in the main hills: (1) the bones are not evenly distributed in the quarry, either in areal distribution or thickness; (2) the quarry floor is characterized by bone bed and by barren areas -- Matthew did not allow the existence of barren ground in his estimate; (3) the pattern of bone distribution in the other quarries on Carnegie Hill was probably most like University Quarry, rather than like the very dense bone bed in the Southwest Excavation.

Table 2 shows the relative amounts of the floor of University Quarry that were occupied by bone bed or were barren. In this quarry, two shallow channels containing bones come together to form a single channel that appears to pass between two low topographic highs on the quarry floor. Barren areas are represented by the topographic highs, the quarry floor lieing between the two bone-filled channels, and smaller isolated patches of floor. The estimate of barren area remains conservative, since large areas of blank space on Barbour's map were not included if they occurred within one of the principal bone-filled channels. Accordingly, the amount of bone bed area for University Quarry could not easily be increased, whereas the amount of barren floor could be so increased to some degree. Since we wish to arrive at a realistic estimate of how much barren floor might be present in University Quarry and similar sites in the main hills, it is better to underestimate the amount of barren ground so that the value we calculate can be considered as a minimum value.

Table 2. Estimation of surface area occupied by bone bed and by barren ground in University Quarry, University Hill, during 1906 - 1908 excavations.

East bone bed	110 sq. ft.
West bone bed	464 sq. ft.
Confluence of the two bone beds	239 sq. ft.
TOTAL BONE BED AREA	813 sq. ft.
Barren quarry floor	288 sq. ft.
Barren topographic highs	79 sq. ft.
TOTAL BARREN AREA	367 sq. ft.
Total area of University Quarry	1180 sq. ft.

These data tell us that at least 30% of the quarry floor was barren ground, without bones or with concentrations so low as to be insignificant in Barbour's field maps. The bone bed itself probably averaged about 15 to 25 bones/sq.ft., based on the earlier calculations of bone density in slabs that have survived to the present. Using the lower value, 813 square feet of bone bed would yield 12,195 bones; the higher value results in 20,325 bones. If these bones all belonged to Menoceras (which they do not), Matthew's method would suggest 60 to 100 rhinoceroses made up the deposit. This seems a reasonable upper limit to the number of Menoceras at University Quarry. The attritional nature of the University Quarry bone bed would suggest that these rhinoceroses did not necessarily die at the same time.

Now Barbour's map clearly indicates that much of the quarry bone bed was not as dense as the blocks which were taken for exhibit, so these estimates are surely on the high side: on the other hand, Barbour's map probably underestimates the depth of the bone bed in places, and fails to record many of the smaller bones in the deposit. As such, the estimate may be about correct.

Let us apply this method of estimation to Carnegie Hill in an attempt to revise Matthew's rhinoceros count. The nucleus of Matthew's estimate is his assumption that in the Southwest Excavation 4100 square feet of quarry floor yielded a density of 40 bones/sq.ft. which, at 200 bones per rhino translates to 820 individuals. Table 3 indicates the area in square feet occupied by the quarries on Carnegie Hill relative to the total surveyed area of the hill itself:

Table 3. Calculation of excavated versus undisturbed areas of Carnegie Hill based on 1983 University of Nebraska field survey.

Total area of Carnegie Hill	102,500 sq.ft.
Area of North Excavation	7,500 sq.ft.
Area of West Excavation	938 sq.ft.
Area of Northwest Excavation	1,875 sq.ft.
Area of Southwest Excavation	10,937 sq.ft.
Undisturbed area	81,250 sq.ft.

Let us revise Matthew's estimate using the following assumptions which better approximate the nature of the bone bed as presently reconstructed: (1) about 30% of the Carnegie Hill bone bed is probably barren; (2) maximum bone density is about 40 bones/sq.ft. but the total area attaining this density is unknown; this area includes the 4100 sq.ft. of the Southwest Excavation worked by Carnegie and American museums and extends eastward into the hill an unknown distance (suggested by bone alignments) -- at a maximum, the area that might be equivalent in bone density to the excavated part of the SW Excavation would be four times the present area of the quarry or about 44,000 sq.ft (this is estimated by simply measuring the total area of a west to east trending strip passing through the hill whose north-south extent is defined by the north-south boundaries of the Southwest Excavation); (3) the remainder of the hill probably would be characterized by densities of about 15-25 bones/sq.ft. Thus,

(a) 102,500 sq.ft. x 30% = 30,750 sq.ft. are probably barren of fossil bone.

(b) 44,000 sq.ft. at a bone density of 40 bones/sq.ft. yield a value of 1,760,000 bones, divided by 200 bones per individual, results in an estimated 8800 individuals.

(c) Let us presume, however, that the actual area with a bone density of 40 bones/sq.ft. is only about twice that of the present Southwest Excavation, thus 8,000 sq.ft. at bone density of 40 bones/sq.ft. = 320,000 bones, divided by 200 bones per individual, yields 1600 individuals. Although much smaller than Matthew's estimate, this still is a very large number of Menoceras.

(d) If 8,000 sq. ft. is employed as an arbitrary areal estimate of the high density bone bed, then the remaining area of the hill with bone bed of low density is 63,750 sq.ft (30,750 sq.ft. are barren). Using a density of 15 bones/sq.ft., we have 956,250 bones and about 4780 individuals. Thus, if the Carnegie Hill bone bed included only rhinoceros, we might estimate that 6380 individuals (1600 + 4780) could be present in the deposit. This is about one-third of Matthew's original estimate.

If even half this number of Menoceras are present in Carnegie Hill, we could still remain skeptical that they are the result of a single catastrophic event. Three thousand to six thousand rhinos are an order of magnitude greater in number than the present day death assemblages of the most abundant ungulate species in East Africa (wildebeest) that result from catastrophic events such as death by drowning and disease. While it is possible that many rhinos could die from severe drought or epidemic disease, it requires additional evidence to advance the idea as a plausible hypothesis. Determination of the age structure of the death assemblage in Carnegie Hill is one approach that could clarify this problem. Such age data are being gathered at the present time.

Matthew also estimated that 500 Moropus and 100 Dinohyus also should be present in the hill. In the case of entelodont, the actual record of skulls and jaws in both hills shows these are very rare. Only two relatively complete skeletons of Dinohyus were ever found in the two hills, and also partial remains of a few other adults and juveniles. The known body count from Carnegie Hill is 3 adults and 2 juveniles. If we extrapolate this to the entire hill as Matthew did, but condition our calculations by our better-founded assumptions, then we estimate the hill could hold about 19 entelodonts. This is about 20% of Matthews's estimate. In the case of chalicothere, we cannot easily arrive at an estimate because it is probable that the distribution of Moropus is nonrandom, influenced by a catastrophic death event; thus the very high density of about 17 individuals in 650 sq.ft. in the Southwest Excavation could be restricted to that small area, and very few other individuals might be present elsewhere in the hill. When we take into account the fact that the Northwest and North Excavations produced many scattered chalicothere bones, we might arrive at the best estimate by combining a bone count from these quarries, and adding to it the 17 to 20 individuals from the Southwest Excavation.

No record of the number and orientation of bones from the North and Northwest Excavations was made in the field, but a census taken in 1981 at the Carnegie Museum showed a minimum number of 14-15 individuals in the Northwest Excavation (based on a count of lower jaws). This totals about 31-35 chalicotheres in the two quarries, but since most of the Southwest Excavation had few to no chalicothere bones, an extrapolation of this value for the entire hill is meaningless. Because of the large size of the bones of chalicothere and entelodont, bone densities of 15-25 bones/sq.ft. are unlikely (two large chalicothere limb bones could fill two square feet by themselves). At least we can be certain that about 35 chalicotheres are present in quarries at the west end of Carnegie Hill.

In summary, Matthew's estimates can today be modified. We can estimate that no more than about 6400 Menoceras are present in Carnegie Hill (probably many less), at most 19 entelodonts, and at least 35 chalicotheres.

Our understanding of the bone bed at Carnegie Hill primarily differs from Matthew's 1923 concept in that (1) Matthew assumed that bones were randomly distributed throughout the hill, but we now know this is not likely to be true; (2) Matthew's estimate of average bone density throughout the Carnegie Hill bone bed is surely too high; (3) the bone bed includes barren areas not considered by Matthew, probably amounting to at least 30% of the surface area under consideration; (4) estimates for the two larger mammals, Moropus elatus and Dinohyus hollandi are too high, possibly by about one order of magnitude; (5) his estimate of the number of individuals of the small rhinoceros Menoceras arikarense is probably three times too high, and I suspect, perhaps by one order of magnitude (1600 rhinos to me is a probable maximum number). The implications of these data are discussed in section 2.5 of this report on the origin of the Agate bone bed.

Epilogue

In 1924, the American Museum did not send a field party to western Nebraska, and in 1925, work centered on the Snake Creek district in southern Sioux County. The summer of 1925 was notable for its focus on Olcott Hill and the discovery of a tooth of 'Hesperopithecus' by the German professor Othenio Abel, who visited the site early that summer. Thomson spent the remainder of the season in the Snake Creek area, working Olcott Hill to find hominid bones, and collecting numerous water-worn mammal bone fragments which he mistakenly believed to be the tools of the supposed primate, later shown to be a peccary. The Agate years were ended, and yet much remained to be learned about the main Agate hills, their geological relationships, and the nature and origin of the bone bed. The period of initial scientific interest was past, and it was to be many years before serious scientific inquiry into Agate's fossils would be made again.

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APPENDIX A

SUMMARY OF EXCAVATIONS, 1904 - 1925

This summary is organized by quarry, and so differs from section 3.0 which is organized by year of excavation. The excavations that have produced the present quarries on Carnegie, University, North Ridge, and Beardog Hills are summarized here under quarry names used on Map A. In the case of Carnegie Hill, these names identify each quarry by its geographic location, and so avoid the institutional bias inherent in the many names given to the same quarry during the early years of excavation.

Here are brought together in one place the various synonyms used for a particular quarry in the main hills. For each excavation, I list the year of excavation, the leader(s), institutional affiliation of the field party, extent of the excavation, and the kinds of fossil mammals unearthed. These fossils are today housed in the leader's affiliate institute unless otherwise noted. Methods employed in each excavation have been omitted, because all field workers used similar methods during this period, chiefly dynamite, horses and scrapers, picks and shovels for the heavy work of rock overburden removal, and the use of hand tools together with the plaster bandage technique for the delicate task of exposing and removing fossils from the quarry floor.

Abbreviations: Me = Menoceros, Mo = Moropus, Di = Dinohyus, Dc = Diceratherium, E = horse, C = camel, O = oreodont, D = deer-like artiodactyl, B = bird, T = turtle, Cr = crocodilian, CA = mammalian carnivore.

CARNEGIE HILL (North Excavation)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1905	Peterson	Carnegie	surface prospect	unknown	Mo,Di,Dc
1906	Utterback	Carnegie	test pit	ca. 10'x 15'	unknown
1906?	Loomis	Amherst	test pit	unknown	unknown
1907	Thomson	American	American Museum Quarry of 1907, Quarry E of H.J. Cook	ca. 15'x 50'	?Me,?Mo

[The 4 above sites are all at the same place on the northeast corner of the hill.]

Year	Leader	Affiliation	Quarry	Extent	Fossils
1916	Thomson	American	test pits	unknown	Me,Mo
1917	Barner	American	stripping of north side	15-20'x 200'	Me,Mo
1919	Thomson	American	north slope, North Side Quarry	10'x 180'	Me,Mo,Di

[From 1916-19, the American Museum developed the small quarry of 1907 at the northeast corner of Carnegie Hill into a major cut that spanned the entire north slope. This cut is still intact today and is named here the North Excavation.]

CARNEGIE HILL (Northwest Excavation)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1906	Utterback	Carnegie	Carnegie Qu. 2, Utterback's West Quarry, Quarry D of H.J. Cook, Utterback Quarry	10-25'x 75'	Me,Mo,Di, C,?E,D,B, CA

[The Northwest Excavation has not been worked on a large scale since Utterback opened the site in 1906; the extent of today's quarry is nearly identical to the cut at the end of work in 1906.]

CARNEGIE HILL (West Excavation)

There is no present record of the field party that produced this small cut of about 1000 sq. feet that today exists as a prominent reentrant on the west face of the hill.

CARNEGIE HILL (Southwest Excavation)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1905	Peterson	Carnegie	Carnegie Qu. 1, Quarry B of H.J. Cook	20'x 45'	Me,Mo,Di, CA
1906	Utterback	Carnegie	Carnegie Qu. 1, Utterback's South Quarry	25'x 45'	Me,Mo,?E, ?CA
1908	Peterson	Carnegie	Carnegie Qu. 1, Quarry F of H.J. Cook	25'x 120'	Me,Mo,Di, Dc,E,C,O, CA,B,T,?D

[From 1905-08, Carnegie Quarry 1 was Peterson's main quarry at Carnegie Hill, producing the greater part of the Carnegie Museum Agate collection. It had grown from a test pit to 120 foot-long cut in three seasons' work. The quarry was relinquished to the American Museum in November 1908.]

Year	Leader	Affiliation	Quarry	Extent	Fossils
1911	Thomson	American	American Museum Quarry, Agate Spring Quarry	18'x 90' within 36'x 125'	Me,Mo,Di, ?CA
1912	Thomson	American	Moropus Quarry, north end of American Museum Quarry	18'x 15' *	Me,Mo
1913	Thomson	American	Moropus Quarry	35'x 70' *	Me,Mo,Di
1914	Thomson	American	Moropus Quarry	20'x 15' and 5'x 6' *	Me,Mo
			*[Only north end of quarry enlarged]		
1914	Sinclair	Princeton	Diceratherium bed Locality 1002A	small area	Me

Year	Leader	Affiliation	Quarry	Extent	Fossils
1916	Thomson	American	Diceratherium bed	ca. 20'x 65'	Me,Mo,Di
1917	Figgins	Denver	Diceratherium bed	unknown	Me,Mo
1919	Thomson	American	Diceratherium bed	large slab, 4.5'x 8.5'	Me,Cr
1920	Thomson	American	Moropus Quarry	20'x 50-100'	Me,Mo
1920	Miller	University of Chicago	Diceratherium bed	slab	Me
1922	Martin	Kansas	?Diceratherium bed	slab	Me
1922	Buettner-Hussey	Michigan	Diceratherium bed	slab	Me

[Thomson's work for the American Museum simply extended Carnegie Quarry 1 into the hill, and farther to the north, while the south boundary of the quarry was unaltered. The Moropus Quarry of the American Museum was located at the north end of the quarry, and the Diceratherium bed at the midpoint and south end. The great mass of Menoceras making up the Diceratherium bed supplied many bone slabs to field parties from 1912 to 1923.]

CARNEGIE HILL (South Excavation)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1922	Thomson	American	prospect 50 yards east of Agate Spring Quarry	small area	Me,Mo
1923	Thomson	American	American Museum Quarry of 1923	50'x 70'	Me,Mo,Di, E,CA

[There is no record of any excavation at this quarry other than the American Museum work in 1923.]

UNIVERSITY HILL (University Quarry)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1904	Peterson	Carnegie	surface prospect	west side of hill	CA
1905	Barbour	Nebraska	University Qu.	15'x 108'	Me,Mo,Di
1906	Barbour	Nebraska	University Qu.	16'x 50'	Me,Mo,Di
1908	Barbour	Nebraska	University Qu.	15'x 50-60'	Me,Mo,Di E,C,CA,B
1908	Lull	Yale	University Qu.	small area at south end of quarry	Me,Mo,Di, CA

[The only excavation placed in University Hill is University Quarry on the hill's west side. University Quarry has remained untouched since 1908.]

NORTH RIDGE (Quarry A)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1904	Peterson	Carnegie	Quarry A of O.A. Peterson, Quarry A of H.J. Cook	ca.25'x 37'	Dc,Me,Di, E,C,O, ?Mo
1906?	Loomis	Amherst	Amherst Point	unknown	unknown

[Since the early excavations by Peterson and Loomis, there is no record of any renewed work at Quarry A on North Ridge.]

BEARDOG HILL (Carnegie Quarry 3)

Year	Leader	Affiliation	Quarry	Extent	Fossils
1904	Peterson	Carnegie	surface prospect	west side of hill	CA
1905	Peterson	Carnegie	Carnegie Qu. 3	?6'x 9'	CA,herbivore bone fragments
1981	Hunt	Nebraska	Carnegie Qu. 3	12'x 12'	CA,C
1982	Hunt	Nebraska	Carnegie Qu. 3	20'x 30'	CA,C

[The discovery of carnivores in burrow fills at this site in 1981-82 suggests that noone excavated at Quarry 3 since it was abandoned in 1905 by Peterson. Little of Beardog Hill has been explored, except for a small area about 20 feet south of Quarry 3 where we placed two test trenches in 1981.]

APPENDIX B

Chemical Analyses of Two Samples of Glass Shards from the Agate Ash Within Agate Fossil Beds National Monument, Sioux County, Nebraska*

*Data courtesy of G.A. Izett, 1968, The Miocene Troublesome Formation in Middle Park, Northwestern Colorado. Part II. Petrography and Chemistry of Ash Beds. U.S. Geological Survey Open-File Report, p.23, tables 2,3. Chemical analyses by U.S. Geological Survey staff:

Sample 74

Location: About 5-10 yds. north of the Agate-Marsland road north of the Niobrara River in SW 1/4, SE 1/4, SW 1/4, sec. 4, T.28N, R.55W, Sioux County, Nebr. (Agate 7.5' topographic quadrangle, 1979). Locality of Evernden et al., 1964, KA 481, 21.3 m.y.

Sample 75

Location: About 0.6 mile east of ranch house [ranger's residence] in Center, N 1/2, SE 1/4, NW 1/4, sec. 10, T.28N, R.55W, Sioux County, Nebr. (Whistle Creek NW 7.5' topographic quadrangle, 1983 prov. ed.). On a small knoll north of two quarry hills [University and Carnegie hills], and about 30 feet below the level of the Agate quarries. This is the Agate Ash on North Ridge.

The samples were collected by G.A. Izett, N.M. Denson, and R.E. Wilcox.

	Sample 74	Sample 75
SiO_2	74.2	74.6
Al_2O_3	12.3	12.1
Fe_2O_3	.66	.60
MgO	.37	.55
CaO	.70	.69
K_2O	6.77	6.30
Na_2O	1.33	1.32
SrO	.010	.009
Rb_2O	.020	.019
MnO	.04	.04
TiO_2	.09	.09
Zn (ppm)	44	37
Cl (ppm)	1200	1200
F (ppm)	500	800
U (ppm)	8	7

Refractive index: 1.496 - 1.498
Color: white (N9)
Shard shape: fibrous to equant frothy shards

APPENDIX C

Fossil Mammals from Carnegie Quarry 3, Beardog Hill, Agate Fossil Beds National Monument, collected by O.A. Peterson and party (1904-1905)

Carnegie Museum #	Taxon	Material	Date	Remarks
1589	Daphoenodon superbus	Partial skeleton	Summer 1905	This is the female genoholotype of Daphoenodon shipped in Box 17 in 1905.
1589a	Daphoenodon superbus	Partial skeleton	Summer 1905	This is the juvenile male found in association with #1589.
1589b	Daphoenodon superbus	Many bones and bone fragments	Summer 1905	"Various bones and fragments found on the surface."
1589c	Daphoenodon superbus	Left hind foot	Aug. 11, 1905	"Left hind foot* found close to where specimens in box 17 was found ...." "Left hind foot found in situ. Part of this specimen is in the museum and is I believe numbered."**
1589d	Daphoenodon superbus	"Limb and foot bones"	Summer 1905	"Note: These bones were found in the talus below where the type of Amphicyon superbus was found. And part of the specimen came from the same block as the latter."
1589e	"Ungulates"	"Various foot bones and sterne-brae"	Summer 1905	"Various foot bones and sternebrae found in the talus below where the type of Amphicyon was found."

APPENDIX C (continued)

1589f	---------	"Various bones and fragments"	Summer 1905	---------------
9645	Carnivore	Bone fragments	Oct. 4, 1905	"These fragments belong with large block in box 17 of 1905 ...the fragments are from the surface."
2389	Paroligobunis simplicidens	Left lower jaw, femur, fibula, and foot bones	Season 1905	"Note= Fragments found in talus below where type of Amphicyon superbus was found."
1602	Phlaocyon annectens	Upper and lower jaws	Aug. 19, 1905	"The specimen was found associated with the type of Amphicyon superbus ... near the Agate Spring Fossil Quarry, in Sioux County, Nebraska." (Peterson, 1907, p. 53)

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* The only evidence that some carnivore material was collected at the quarry in 1904 is this entry which appears in Peterson's handwritten box list for 1905: "Bx. 22 -- One hind foot and fragments found by washing dirt, and belong with carnivore specimen collected in 1904." Presumably the carnivore specimen collected in 1904 was found at the time of the discovery of Quarry 3 by the Carnegie party.

** It is certain that the pair of articulated skeletons collected in a single block of sandstone from Quarry 3 in 1905 (CM 1589 and CM 1589a) were shipped in Box 17. Thus references to discovery of material close to or in association with the beardogs in Box 17, one of which is the type of <u>Daphoenodon superbus</u> (originally believed to be "Amphicyon" by Peterson), indicates that such fossils come from Quarry 3 and possibly were closely associated with the Box 17 beardogs.

Box 17 and later boxes were almost surely collected after July 27, 1905, since Peterson returned to the field about that time (based on notes in Pepperberg's field diary recording a visit by Peterson and his wife); the first 16 Carnegie boxes were collected by T.F. Olcott alone, Box 17 being the first box packed following Peterson's return to the field in late July.

Quoted remarks listed above are taken from Peterson's field labels at the Carnegie Museum, unless otherwise noted.

APPENDIX D

Fossil mammals from Carnegie Quarry 2 (Northwest Excavation), collected by W.H. Utterback in 1906

CHALICOTHERE MOROPUS

Material		**Carnegie No.**	**Dental Wear Stage**
Upper teeth		1596	----
---		1605	----
Forelimb, composite forefoot		1700	----
Hindlimb, composite hindfoot		1701	----
Lower jaws (R-L)		1702/15758	4A or 4B
Vertebrae		1703	----
Innominates (R-L)		1705	----
Skull, disarticulated		1707	----
Upper jaw (L),	(y)	1709	----
Hindfeet, 2 composite (L)		1710	----
Lower jaws (R-L),	(y)	1711	----
Vertebrae		1712	----
Vertebrae	(y)	1713	----
Vertebrae		1714	----
Vertebra		1715	----
Vertebra		1716	----
Vertebra		1717	----
Vertebra		1718	----
Vertebra		1719	----
Vertebrae		1720	----
Vertebrae		1721	----
Vertebrae		1722	----
Vertebrae		1723	----
Vertebrae		1724	----
Vertebrae		1725	----
Vertebra, atlas		1726	----
Vertebra, atlas		1727	----
Vertebra, atlas		1728	----
Vertebra, atlas		1729	----
Vertebra		1730	----
Scaphoid, metapodial, phalanx, vertebra		1731	----
Upper jaws (R-L)		1732	----
Basicranium, partial		1733	----
Basicranium, partial		1734	----
Basicranium, partial		1735	----
Basicranium, partial		1736	----
Occipital condyle		1737	----
Upper jaw (R),	(y)	1738	----
Lower jaw (L), skull fragments,	(y)	1739	3
isolated teeth		1740	----
Upper jaws (R-L)		1741	----
Upper jaw fragments		1742	----
Upper jaw (R),	(y)	1743	----
Lower jaws (R-L)		1744	4A
Isolated teeth		1745	----
Upper jaw fragment (L), isolated teeth		1746	----

APPENDIX D (continued)

Upper jaw (R), partial	(y)	1747	----
Lower jaw (R)		1748	3
Isolated teeth		1749	----
Lower jaws (R-L)		1750	4A
Lower jaws (R-L)		1751	4B
Lower jaws (R-L)		1752	3
Lower jaws (R-L)		1753	4C
Lower jaws (R-L)		1754	5
Lower jaws (R-L),	(y)	1755	2
Lower jaw (L),	(y)	**1756	----
Lower jaw (L)		1757	----
Lower jaws (R-L)		1758	4C
Lower jaws (R-L)	(y)	1759	3
Ribs		1760	----
Ribs		1761	----
Ribs		1762	----
Ribs, sternebra		1763	----
Scapula (L), small		1764	----
Scapula (L), small		1765	----
Scapula (R),	(y)	1766	----
Scapula (L), small		1767	----
Scapula (L),	(y)	1768	----
Scapula (R),	(y)	1769	----
Scapula (R), large		1770	----
Scapulae (R-L), large		1771	----
Scapula (L), medium		1772	----
Scapula (L), medium		1773	----
Scapula (L), medium		1774	----
Scapulae (R-L)		1775	----
Scapula (L), very large		1776	----
Humerus (L),	(y)	1777	----
Radio-ulna (R)		1778	----
Ulna (R), proximal radius		1779	----
Radio-ulna (L)		1780	----
Ulna (R), proximal ulna (L)		1781	----
Radio-ulnae (R-L)		1782	----
Radius (R-L),	(y)	1783	----
Radius (R),	(y)	1784	----
Radius (R),	(y)	1785	----
Radio-ulna (R)		1786	----
Femur (L), tibia (R-L)		1787	----
Femur (R)		1788	----
Femur (R-L), tibia (R-L)	(y)	1789	----
Tibia (R), medium		1790	----
Tibia (R-L), small		1791	----
Tibia (L), large		1792	----
Innominate (R-L), large		1793	----
Innominate (R), fragment		1794	----
Innominate (R)		1795	----
Hind limb (R-L)		1796	----
Ilium (R), fragment	(y)	1797	----
Ilium (L), fragment		1798	----
Innominate, fragment, large		1799	----

APPENDIX D (continued)

Forefoot, composite	1800	----
Forefoot, composite	1801	----
Forefoot (R), composite	1802	----
Forefoot, composite	1803	----
Forefoot, composite	1804	----
Forefoot, composite	1805	----
Forefoot, composite	1806	----
Forefoot, composite	1807	----
Forefoot (L), partial	1808	----
Metacarpals III, IV	1809	----
Metacarpals, associated	1810	----
Metacarpals	1811	----
Hindfoot (R-L), composites	1812	----
Hindfoot (L), composite	1813	----
Hindfoot, composite	1814	----
Hindfeet, 2, possibly associated	1815	----
Metapodials (R)	1816	----
Metatarsals (L)	1817	----
Metatarsals (L)	1818	----
Skull fragments	1819	----
Vertebrae, caudal	1823	----

RHINOCEROS MENOCERAS

Material		**Carnegie No.**	**Dental Wear Stage**
Lower jaw (L),	(y)	1820	1
Lower jaw (L),	(y)	1821	1
Back of skull, teeth, foot bones		1822	----
Lower jaw (R),	(y)	2462	1
AMPHICYONID CARNIVORE			
Astragalus		1824	----
CAMELID			
Astragalus		1825	----
MOSCHID OR HYPERTRAGULID			
Astragalus		1826	----
ENTELODONT DINOHYUS			
Incisor		1827	----
EQUID PARAHIPPUS			
Upper jaw (R), P4-M1		*1598	----
ACCIPITRID GERANOAETUS			
Tarsometatarsus		1828	----

Symbols: R = right, L = left, y = young individual,
* = not certainly from Carnegie Quarry 2
** = sent to Lehigh University in 1955

APPENDIX E

FOSSIL MAMMALS FROM UNIVERSITY QUARRY, UNIVERSITY HILL, 1906 - 1908

Map I #	Barbour's Field #	Skeletal Element	Taxon	Bearing of Long Axis
Fossil Mammal Bones collected in 1906				
1	1	radius	Moropus	N61W
2	2	ulna	Moropus	N68W
3	3	radius	Moropus	N45W
4	4	lower jaw	Menoceras	N33E
5	5	lower jaw	Menoceras	N41W
6	6	lower jaw	Menoceras	N12E
7	7	scapula	Menoceras	N43E
8	8	vertebra	Menoceras	N87E
9	9	rib	Menoceras	N46W
10	10	rib	Menoceras	N31W
11	11	rib	Menoceras	N33W
12	12	humerus	Menoceras	N31W
13	13	femur	Menoceras	N63E
14	14	innominate	Menoceras	----
15	15	?limb bone	----	N68W
16	16	humerus	Menoceras	N47W
17	17	femur	Menoceras	N25W
18	18	humerus	Menoceras	N34W
19	19	femur	Menoceras	N58W
20	20	femur	Menoceras	N48W
21	21	tibia	Menoceras	N28E
22	22	lower jaw	Moropus	N78E
23	23	skull	Menoceras	----
24	24	vertebra	Menoceras	----
25	25	tibia	Menoceras	N32W
26	26	atlas vertebra	Menoceras	----
27	27	partial lower jaw	Menoceras	N46E
28	28	femur	Menoceras	N24E
29	29	innominate	Menoceras	----
30	30	innominate	Menoceras	----
31	31	tibia, fibula	Menoceras	N87E
32	32	rib	Menoceras	N90E
33	33	vertebra	Menoceras	----
34	34	vertebra	Menoceras	----
35	35	vertebra, scapula,	Moropus,	----
		ulna, ribs, ?jaw	Menoceras	----
36	36	vertebra	Menoceras	N82W
37	37	foot bones(aligned)	Menoceras	N48W
38	38	ulna, radius	Menoceras	N62W
39	39	partial innominate	Menoceras	N41W
40	40	humerus	Menoceras	N30E
41	41	limb bone	Menoceras	N18W
42	42	humerus	----	N14W
43	43	limb bone	Menoceras	N42W

44	44	rib	----	N44W
45	45	vertebrae	Menoceras	----
46	46	?limb bone	----	N16W
47	47	partial ulna	----	N22W
48	48	partial ulna	----	N35E
49	49	partial ulna	----	N33W
50	50	partial radius	----	N51W
51	51	partial ulna	----	N90E
52	52a	rib	Moropus	N35E
53	53b	rib	Moropus	N35E
54	54c	limb bone	Menoceras	N50E
55	55d	innominate	Menoceras	----
56	56e	humerus	Moropus	N23E
57	57f-g	radius, ulna	Moropus	N21E
58	58h	vertebra	Moropus	----
59	59i	lower jaw	Moropus	N6W
60	60j	limb bone	Menoceras	N3E
61	61k	?lower jaw	?Moropus	N42E
62	62l	phalanx	Moropus	N
63	63m	limb bone	Menoceras	N85E
64	64n	lower jaw	Moropus	N9W
65	65o	scapula	Moropus	N27W
66	66p	skull	Menoceras	----
67	67q	femur	Menoceras	N24W
68	68r	lower jaw	Menoceras	N13W
69	69s	humerus	Menoceras	N15W
70	70t	skull	Menoceras	----
71	71u	metapodial	----	N15W
72	72v	metapodial	Moropus	N63W
73	73w	bone fragments	----	----
74	74x	partial scapula	Moropus	N8E
75	75y	partial humerus	Moropus	N4E
76	76z	calcaneum	Moropus	N5W
77	77a'	femur	Moropus	N29W
78	78b'	vertebra	Moropus	N90E
79	79c'	calcaneum	Moropus	N11W
80	80d'	vertebra	Moropus	----
81	81e'	tibia	Menoceras	N15E
82	82f'	tooth	Dinohyus	N15W
83	83g'	vertebra	Moropus	----
84	84h'	sacrum	Moropus	----
85	85i'	vertebra	----	----
86	86j'	lower jaw	Menoceras	N23W
87	87k'	lower jaw	Menoceras	N16W
88	88l'	lower jaw	Menoceras	N83E
89	89m'	vertebra	Moropus	----
90	90n'	limb bone	Menoceras	N1W
91	91o'	radius, ulna	Menoceras	N82E
92	92p'	tibia	Menoceras	N15E
93	93I	lower jaw	Moropus	N41W
94	94II	lower jaw	Moropus	N13W
95	95III	axis vertebra	----	----
96	96IV	rib	Menoceras	N27W
97	97V	vertebra	Moropus	----
98	98VI	atlas vertebra	----	----

99	99VII	humerus	?Menoceras	N54W
100	100VIII	femur	Menoceras	N87E
101	101IX	rib	Moropus	N7E
102	102X	atlas vertebra	Menoceras	----
103	103XI	vertebra	Menoceras	----
104	104XII	lower jaw	Moropus	N34E
105	105XIII	metacarpal	Moropus	N11E
106	106XIV	partial lower jaw	----	N58W
107	107XV	vertebra	----	----
108	108XVI	lower jaw	Menoceras	N38E
109	109XVII	lower jaw	Moropus	N24W
110	110XVIII	radius, ulna	Moropus	N33W
111	111XIX	?bone fragment	----	N62W
112	112XX	lower jaw	Menoceras	N63W
113	113XXI	limb bone	Menoceras	N32W
114	114XXII	?metapodial	Menoceras	N29E
115	115XXIII	humerus	Menoceras	N25W
116	116XXIV	partial innominate	----	N74W
117	117XXV	vertebra	Menoceras	----
118	118XXVI	lower jaw	Menoceras	N74E
119	119XXVII	tooth	Dinohyus	----
120	120XXVIII	vertebra	Menoceras	----
121	121XXIX	partial ulna	----	----
122	XIVa	lower jaw	?Menoceras	N5W

Fossil Mammal Bones collected in 1908

123	1K	canine tooth	Dinohyus	----
124	2B	tibia	----	----
125	3K	tibia	----	----
126	4K	tibia	----	----
127	5K	ulna	----	----
128	6K	rib	----	----
129	7K	canine tooth	Dinohyus	----
130	8K	tibia	----	----
131	9K	atlas vertebra	----	----
132	10K	canine tooth	Dinohyus	----
133	11V	tibia	----	----
134	12V	fibula	----	----
135	13K	vertebra (slab)	----	----
136	14B	skull (slab)	Menoceras	----
137	15K	incisor	Dinohyus	----
138	16K	incisor	Dinohyus	----
139	17K	vertebra	----	----
140	18V	pelvis	Moropus	----
141	19B	skull	Menoceras	----
142	20B	femur	----	----
143	21B	femur	----	----
144	22D	calcaneum,astragalus	----	----
145	23B	tibia	----	----
146	24B	humerus	----	----
147	25V	skull, jaws	Dinohyus	----
148	26B	vertebra	----	----
149	27B	vertebra	----	----
150	28B	pelvis	----	----

151	29D	tibia	----	----
152	30D	femur	----	----
153	31D	atlas vertebra	----	----
154	32D	axis vertebra	----	----
155	33D	femur	----	----
156	34D	femur	Moropus	----
157	35D	tibia	----	----
158	36D	femur	Moropus	----
159	37B	tibia	----	----
160	38K	femur	Moropus	----
161	39K	ulna	Moropus	----
162	40K	vertebra	Moropus	----
163	41K	vertebra	Moropus	----
164	42K	vertebra	Moropus	----
165	43K	vertebra	Moropus	----
166	44K	femur	Moropus	----
167	45B	humerus	----	----
168	46B	vertebra (slab E)	Dinohyus	----
169	47B	canine tooth	Dinohyus	----
170	48B	femur	Menoceras	----
171	49B	atlas vertebra	Dinohyus	----
172	50B	tooth	Dinohyus	----
173	51B	scapula	Dinohyus	----
174	52B	metapodial	----	----
175	53D	pelvis	----	----
176	54K	cervical vertebra	Moropus	----
177	55K	ribs,scapula (slab)	Moropus	----
178	56K	?tibia	----	----
179	57K	?tibia	----	----
180	58B	axis vertebra	----	----
181	59B	tibia	----	----
182	60B	atlas vertebra	----	----
183	61B	tibia	----	----
184	62B	fibula	----	----
185	63EH	vertebra	----	----
186	64EH	tibia	----	----
187	65D	radius	----	----
188	66D	humerus	----	----
189	67EH	scapula	Dinohyus	----
190	68EH	rib	----	----
191	69EH	scapula	Dinohyus	----
192	70EH	calcaneum	----	----
193	71EH	vertebra	----	----
194	72B	scapula	Menoceras	----
195	73B	jaw	Menoceras	----
196	74B	scapula	Dinohyus	----
197	75B	femur	----	----
198	76B	rib (slab)	Dinohyus	----
199	77B	vertebra	----	----
200	78B	vertebra	----	----
201	79EH	vertebra	----	----
202	80D	vertebra (slab)	----	----
203	81EH	humerus	----	----
204	82EH	scapula	----	----
205	83EH	jaw	----	----

206	84EH	phalanx	Moropus	----
207	85EH	jaw, axis (slab)	----	----
208	86K	sacrum	----	----
209	87K	rib, 2 metacarpals	Dinohyus	----
210	88B	----	----	----
211	89K	tibia	----	----
212	90D	patella	Moropus	----
213	91D	phalanx	Dinohyus	----
214	92D	vertebra	----	----
215	93D	canine tooth	Dinohyus	----
216	94B	2 ribs	Dinohyus	----
217	95B	astragalus	Dinohyus	----
218	96B	lunar	Dinohyus	----
219	97EH	slab	----	----
220	98EH	slab	----	----
221	99EH	vertebra (slab)	----	----
222	100EH	slab with bird bones	----	----
223	101EH	slab	----	----
224	102K	?tibia	----	----
225	103K	tibia, fibula	----	----
226	104D	two jaws (slab)	Menoceras	----
227	105K	rib	----	----
228	106B	slab	----	----
229	107K	axis vertebra	----	----
230	108	slab	----	----
231	109K	humerus	----	----
232	110K	skull	Moropus	----
233	111D	astragalus	Moropus	----
234	112D	rib	----	----
235	113B	jaw	Menoceras	----
236	114B	fibula	----	----
237	115B	jaw	Menoceras	----
238	116EH	axis vertebra	Dinohyus	----
239	117EH	slab (to Yale)	Dinohyus, etc.	----
240	118K	humerus	----	----
241	119K	rib	?Moropus	----
242	120B	fibula	----	----
243	121B	scapula	----	----
244	122B	scapula	----	----
245	123K	humerus	Moropus	----
246	124EH	scapula	Dinohyus	----
247	125EH	rib	----	----
248	126EH	femur	?Dinohyus	----
249	127K	ulna	Moropus	----
250	128Gibb	pelvis	Dinohyus	----
251	129Gibb	femur (Yale slab)	Dinohyus	----
252	130Gibb	tibia (Yale slab)	Dinohyus	----
253	131EH	tibia	Dinohyus	----
254	132EH	rib	Dinohyus	----
255	133	----	----	----
256	134B	phalanx	Moropus	----
257	135B	humerus	Menoceras	----
258	136K	humerus	----	----
259	137EH	rib	----	----
260	138D	vertebra	Dinohyus	----

261	139EH	radius	Menoceras	----
262	140EH	rib	Dinohyus	----
263	141B	slab	----	----
264	142Gibb	phalanx	Dinohyus	----
265	143EH	phalanx	Dinohyus	----
266	144EH	slab	Menoceras	----
267	145EH	slab	Menoceras, bird bones, Carnivora	----
268	146EH	slab(2 metatarsals)	Dinohyus	----
269	147EH	calcaneum	Dinohyus	----
270	148EH	astragalus	Dinohyus	----
271	149D	humerus	Dinohyus	----
272	150D	2nd upper incisor	Dinohyus	----
273	151EH	rib	Dinohyus	----
274	152EH	rib	Dinohyus	----
275	153EH	rib	Dinohyus	----
276	154EH	rib	Dinohyus	----
277	155B	ulna	Dinohyus	----
278	156	ulna	Dinohyus	----
279	156.5	humerus	Moropus	----
280	157	pelvis	Menoceras	----
281	158	partial skull (see #110)	Moropus	----
282	159	patella (contacts tibia #131EH)	Dinohyus	----
283	160	rib	Dinohyus	----
284	161	upper incisor	Dinohyus	----
285	162	vertebrae (slab)	Dinohyus	----
286	163EH	slab	----	----
287	164EH	2-3 cervical vertebrae	Dinohyus	----
288	165B	patella	Moropus	----
289	166K	jaw	Moropus	----
290	167K	jaw	Menoceras	----
291	168D	metacarpal	Dinohyus	----
292	169D	phalanx	Dinohyus	----
293	170D	scaphoid	Dinohyus	----
294	171D	canine tooth	Dinohyus	----
295	172D	canine tooth	Dinohyus	----
296	173B	jaw	Menoceras	----
297	174B	jaw	Moropus	----
298	175EH	humerus	Dinohyus	----
299	176	phalanx	Dinohyus	----
300	177	phalanx	Dinohyus	----
301	178EH	slab	----	----
302	179B	tibia	Menoceras	----
303	180K	vertebra	Moropus	----
304	181B	radius	Moropus	----
305	182K	rib (slab 6)	Moropus	----
306	183K	vertebra (slab 6)	----	----
307	184B	vertebra (slab 6)	----	----
308	185B	vertebra (slab 6)	----	----
309	186B	vertebra (slab 6)	----	----
310	187B	vertebra (slab 6)	----	----

311	188	block A	----	----
312	189	block B	----	----
313	190	block C	----	----
314	191	block D	----	----
315	?192	SLAB I (to Yale)	----	----
316	193	SLAB II	----	----
317	194	SLAB IV	----	----
318	---	SLAB V	Dinohyus	----
319	---	SLAB VI	----	----

Note: SLAB III which burned in March 1912 apparently was not given a field number by Barbour.

APPENDIX F

Fossil mammals from Carnegie Quarry 1 exclusive of the common taxa Menoceras, Moropus, and Dinohyus, 1904 - 1984

EQUIDS

Taxon	Carnegie Mus. #	Material	Location in quarry (See Map E)
Parahippus	2202	maxilla with dp1-4	Section 11
Parahippus	2203	isolated molar	Section 14
Parahippus?	2204	premolar	----
Parahippus	2115	upper and lower cheek teeth	----
Parahippus	9632	upper cheek tooth	----
equid	1894	proximal phalanx of lateral digit	Sections 3-7 (Olcott 1905)

OREODONTS

Taxon	Carnegie Mus. #	Material	Location in quarry (See Map E)
Merychyus?	1902	metapodial fragments	Sections 3-7 (Olcott 1905)
oreodont	2189	phalanx	Section 17
Merychyus	2194	left M1 in lower jaw fragment	Section 10
Merychyus?	2195	isolated tooth	----

CAMELIDS

Taxon	Carnegie Mus. #	Material	Location in quarry (See Map E)
camelid	1833	large astragalus	----
camelid (cf. Stenomylus)	2189,2192, 2196,2197, 2195A	teeth and podials	----
camelid (cf. Stenomylus)	2190	?podials	Sections 16-17
Stenomylus	2191	teeth in partial jaw	----

HYPERTRAGULID

Taxon	Carnegie Mus. #	Material	Location in quarry (See Map E)
Nanotragulus?	2225	lower left cheek tooth	Location uncertain: specimen label reads Quarry 1, but field label reads 1 mile E of Agate Quarries.

APPENDIX F (continued)

CARNIVORA

amphicyonid Cynelos	2200	left lower M1	----
amphicyonid	2201	lower jaw fragment with tooth	Section 17
amphicyonid	2199	----	----
amphicyonid	9631	lower teeth	----
carnivore	1895	tooth & foot bone, in association	Sections 3-7 (Olcott 1905)

BIRDS

eagle (see Wetmore 1926)	2207	talon	Quarry 1
bird	11365	----	?Quarry 1

TURTLE

small turtle	2206	humerus	Section 10 or 12

APPENDIX G

Alignment of mammal bones in the West Bone Bed of University Quarry, University Hill, Agate Fossil Beds National Monument (1906)

NORTH	Frequency	NORTH	Frequency
0 - 10	>>>>>>	0 - 10	>>>>
11 - 20	>>>>>>>>>>	11 - 20	>>>>
21 - 30	>>>>>>>>>>	21 - 30	>>>>>>
31 - 40	>>>>>>>>	31 - 40	>>>>>>
41 - 50	>>>>>>>>>>>	41 - 50	>>>>
51 - 60	>>>	51 - 60	
61 - 70	>>>>>>>	61 - 70	>
71 - 80	>	71 - 80	>>
81 - 90	>	81 - 90	>>>>>>>>>
WEST		EAST	

The frequency diagrams indicate the long axis alignments of bones from the 1906 excavation of the west bone bed at University Quarry. Each symbol (>) represents the alignment of one bone. These alignments can range over 180 degrees of arc. Highest frequencies occur from North 11 to 50 degrees West, suggesting the possibility of a northwest-southeast alignment mode; the channel axis that can be seen on the west side of University Hill also appears to have a northwest-southeast alignment. The bearing of the long axis of each bone (N=93) was measured with a protractor on Barbour's original field map of the bones in the quarry, and the bearing was expressed in either the NW or NE quadrant.

APPENDIX H

Thomson's Field List of Chalicotheres from the American Museum Moropus Quarry, Southwest Excavation, 1912-1920

1912

No. 1. (AMNH 14377) Skull, jaws, scapulae, humeri, ulna, radii, cervicals and a few dorsals, ribs, misc. foot bones.

No. 2. (AMNH 14376) Skull and jaws, nearly complete series of vertebrae, cervicals, ribs, scapulae, humeri, ulnae, radii, and some foot bones.

No. 3. (AMNH 14375) Very large and nearly complete skull, ulna and radius, foot bones, atlas, femur.

No. 4. (AMNH 14378) Skull.

No. 5. (AMNH 14379) Skull.

1913

No. 6. (AMNH 14419) Two and possibly a third individual, disarticulated and badly mixed; parts of three skulls under this number. Bad condition. Two blocks and many small packages.

No. 7. (AMNH 14417) Skull and greater part of skeleton in very good state of preservation.

No. 8. (AMNH 14418) Skull, jaws, and greater part of skeleton. Very large individual and well preserved. One very large block. Many small blocks and packages.

No. 8A. (AMNH -----) Limb bones etc. found near or mixed with No. 8. Many of these bones probably belong with specimen No. 11 which was collected in 1914.

No. 9. (AMNH -----) Jaws and limb material, apparently very interesting material, but not all taken out this season. Good prospect.

No. 10. (AMNH -----) Skeletal material (young individuals), apparently two individuals. One large block and many small pasted and wrapped pieces.

No. 11. (AMNH -----) Jaws taken out. More material running in, but left for next season. Good prospect.

No. 12. (AMNH -----) Foot bones and ribs taken out. Both ulnae and radii left for next season. Good prospect.

APPENDIX H (continued)

1914

This season was spent in collecting specimens which we had located in 1913. The numbers were given to them in 1913.

No. 9 and 9A. (AMNH -----) Skull, jaws, and greater part of skeleton. This number represents at least two individuals, one large and one small.

No. 11. (AMNH -----) Two individuals, one large and one small. Greater part of the two skeletons represented, and also a third. No skulls known but may be in block.

No. 12. (AMNH -----) Skull, jaws, and more or less of skeleton.

1916

No. 13. (AMNH -----) Skull, some limb and foot bones, pelvis, and a few vertebrae.

No. 14. (AMNH -----) Skull and jaws, pelvis, limb and foot bones, ribs and vert. few. (Small type of *Moropus*).

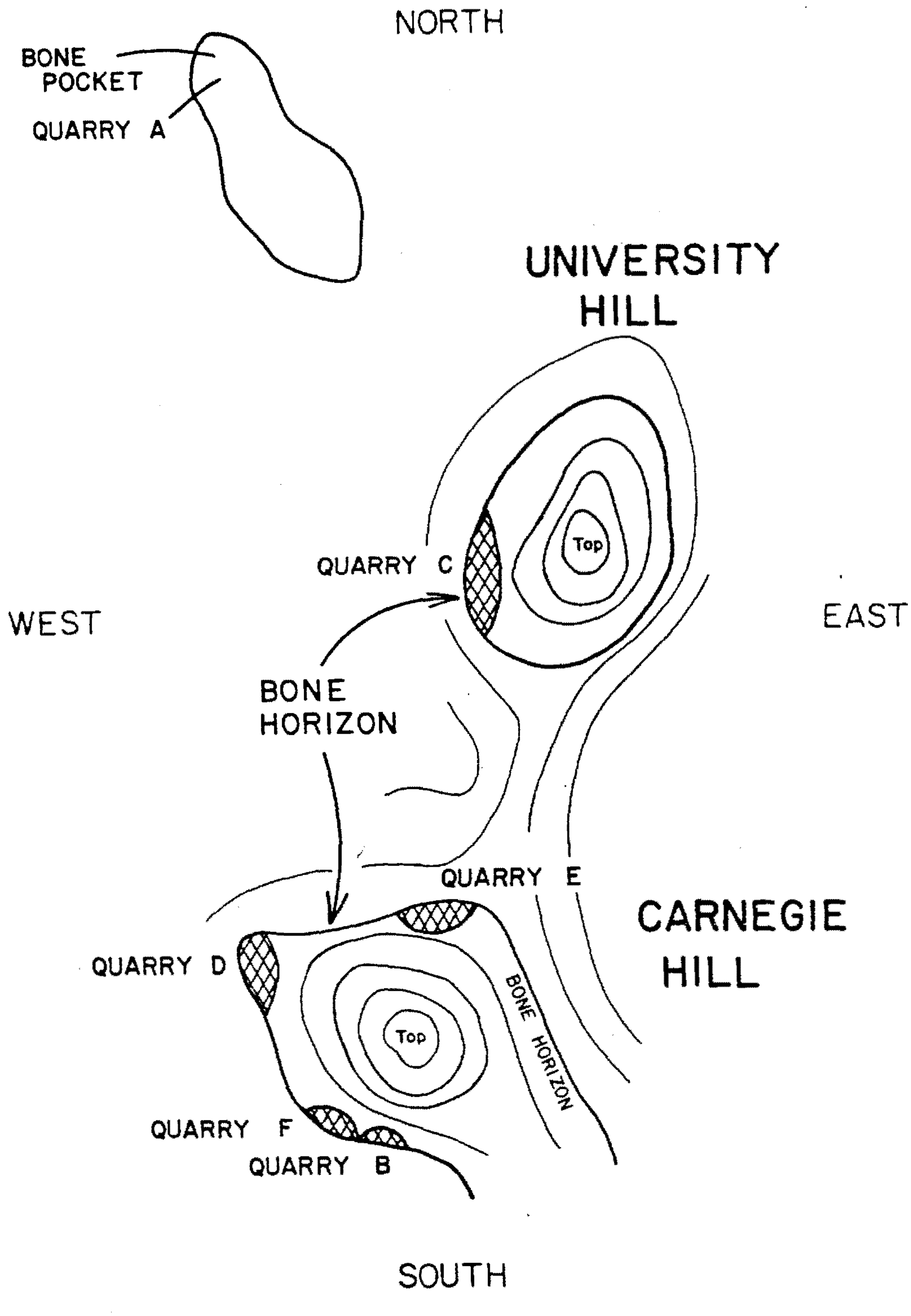
1920

For convenience of record I have numbered this season's *Moropus* material No. 15 to 16 to be kept in one lot until prepared and assembled with *Moropus* skeletons already prepared at the Museum.... The last large *Moropus* skeleton No. 16 consisted of nearly all the ribs, hind limbs, lumbars. [Part?] of pelvis, and possibly skull and jaws belong to this individual and also a very large scapula, ulna, radius and humerus all numbered 15. A few bones under No. 18 were found near what we called the bank and rather higher than the rest.

This appendix is quoted directly from Albert Thomson's field notebook in the archives of the Department of Vertebrate Paleontology, American Museum of Natural History, New York.

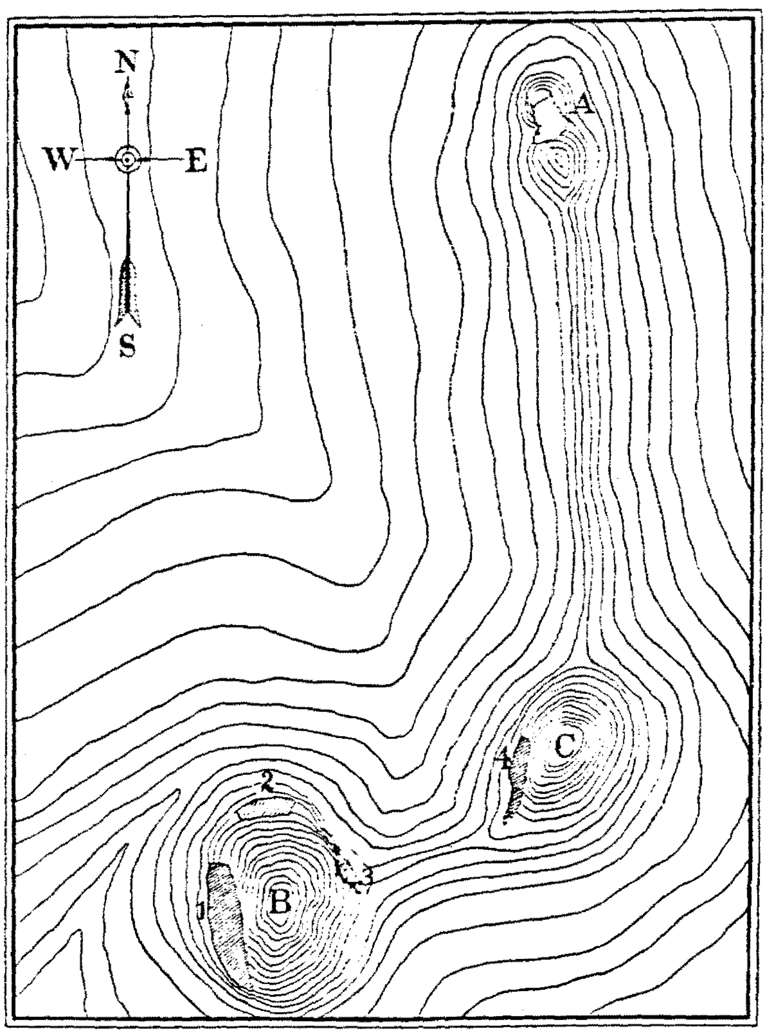
MAPS OF THE AGATE QUARRIES

MAP B



Unpublished map of the Agate quarries prepared by Harold Cook circa 1911. Cook assigned letter designations to the early excavations. The small size and limited lateral extent of quarries B, E, and F indicate that the sketch was made before these sites were converted into much larger quarries by the American Museum from 1911 to 1920 (see Appendix A).

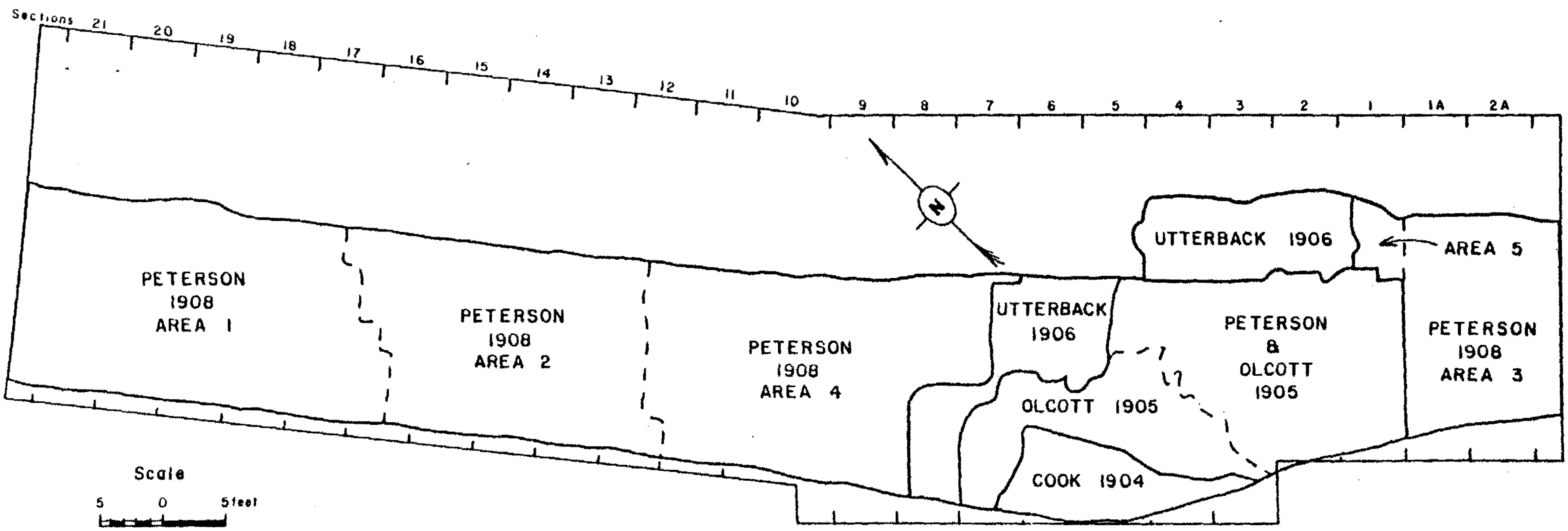
This published map (Holland and Peterson, 1914) of the Agate Quarries produced by W.J. Holland shows an approximately correct relationship between the various early quarries, but is incorrectly aligned with true north (see Map A). The quarries as identified today are: A, Carnegie Quarry A; 1, Southwest Excavation (including Carnegie Quarry 1); 2, Northwest Excavation (Carnegie Quarry 2); 3, test excavation of 1906 that developed into the American Museum Quarry of 1907; 4, University Quarry.



Rough outline topographical map of the Agate Spring Fossil Quarries drawn by W. J. Holland. A, quarry opened by Mr. O. A. Peterson in 1904. B, "Carnegie Hill." 1 and 2, quarries opened by Carnegie Museum. 3, openings made by F. B. Loomis and subsequently worked by a party from the A. M. N. H. C, "University Hill." 4, quarry opened by Prof. E. H. Barbour.

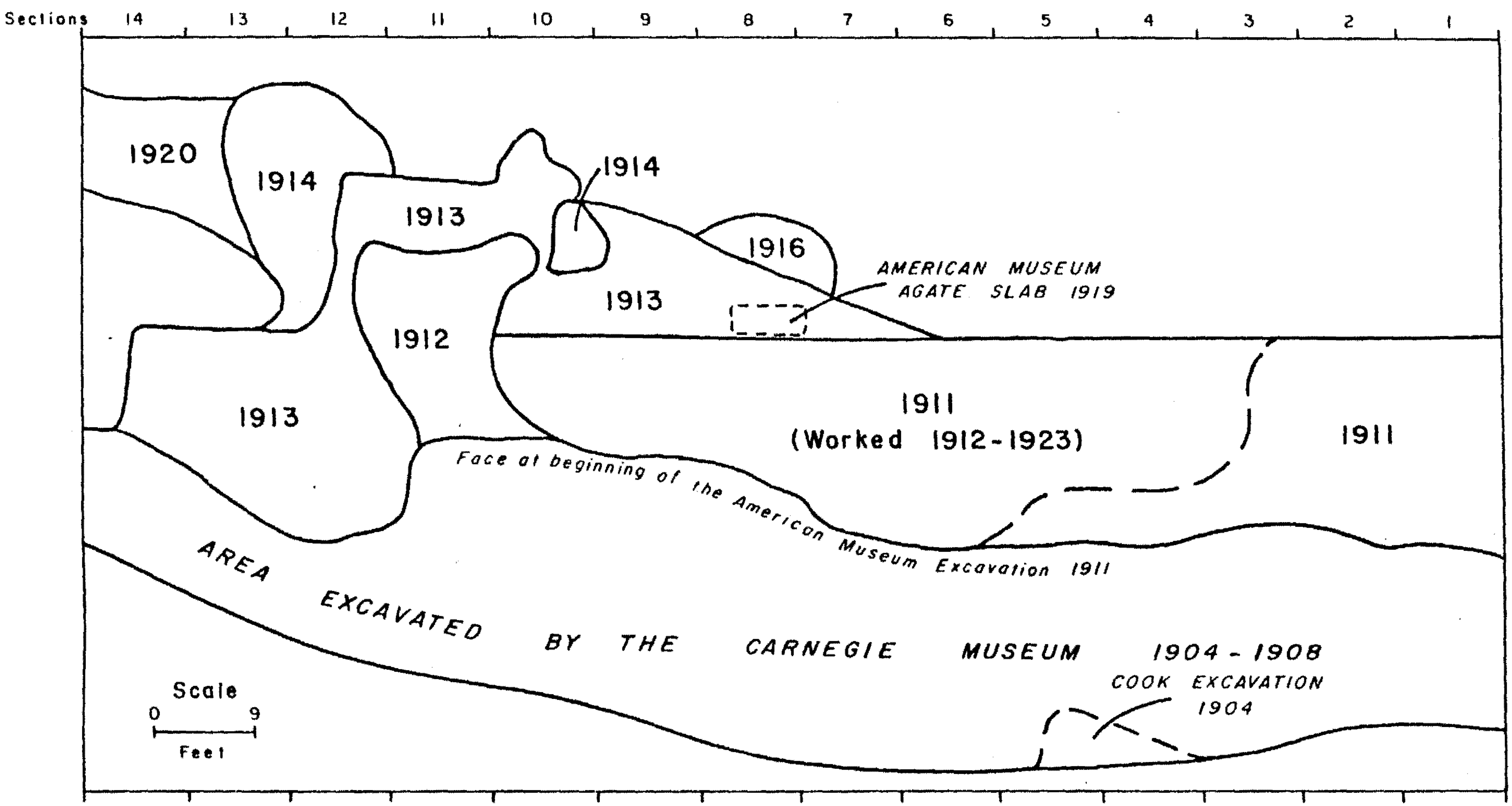
MAP D

The sequence of excavations carried out by the Carnegie Museum from 1904 through 1908 established the Southwest Excavation on Carnegie Hill. O.A. Peterson and W.H. Utterback supervised work in this quarry. The site was relinquished in 1908 to the American Museum, and the excavation was further enlarged from 1911 to 1920 (see Map F).



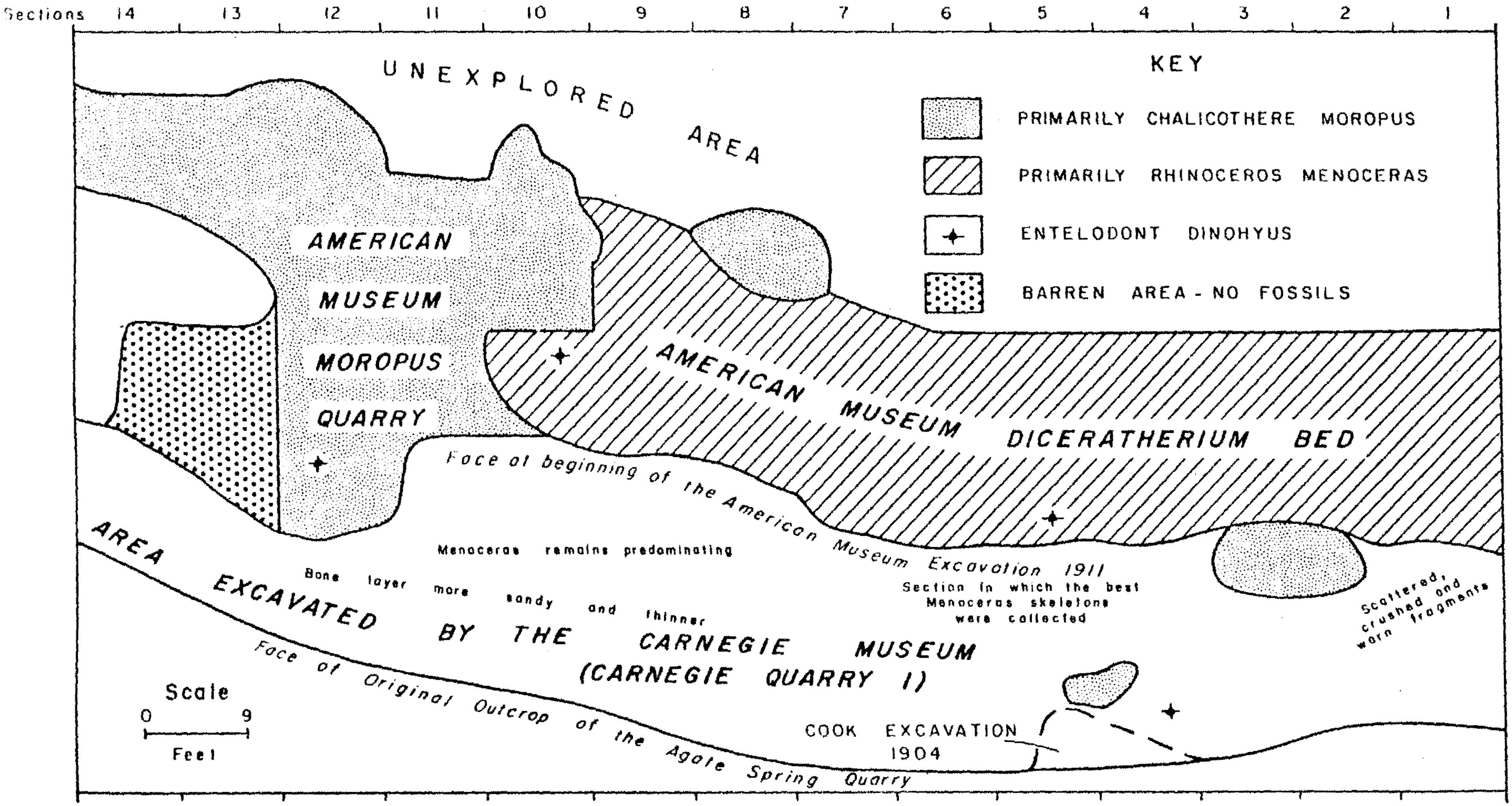
Sequence of Excavations in Carnegie Quarry 1 (1904 - 1908)

MAP F



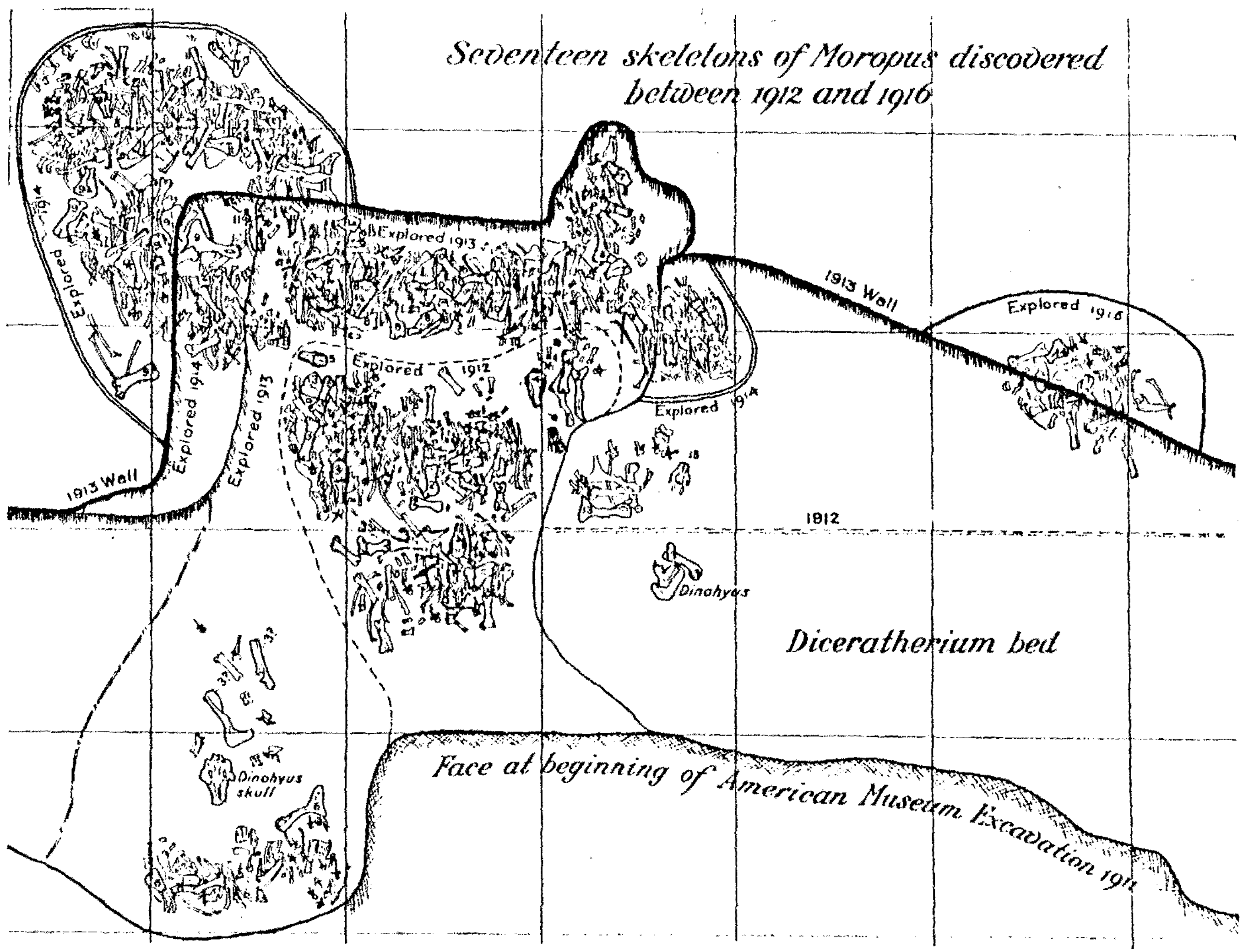
Sequence of Excavations in the Southwest Excavation (1904 - 1920)

MAP G



Fossil Mammal Distribution in the Southwest Excavation (1904 - 1920)

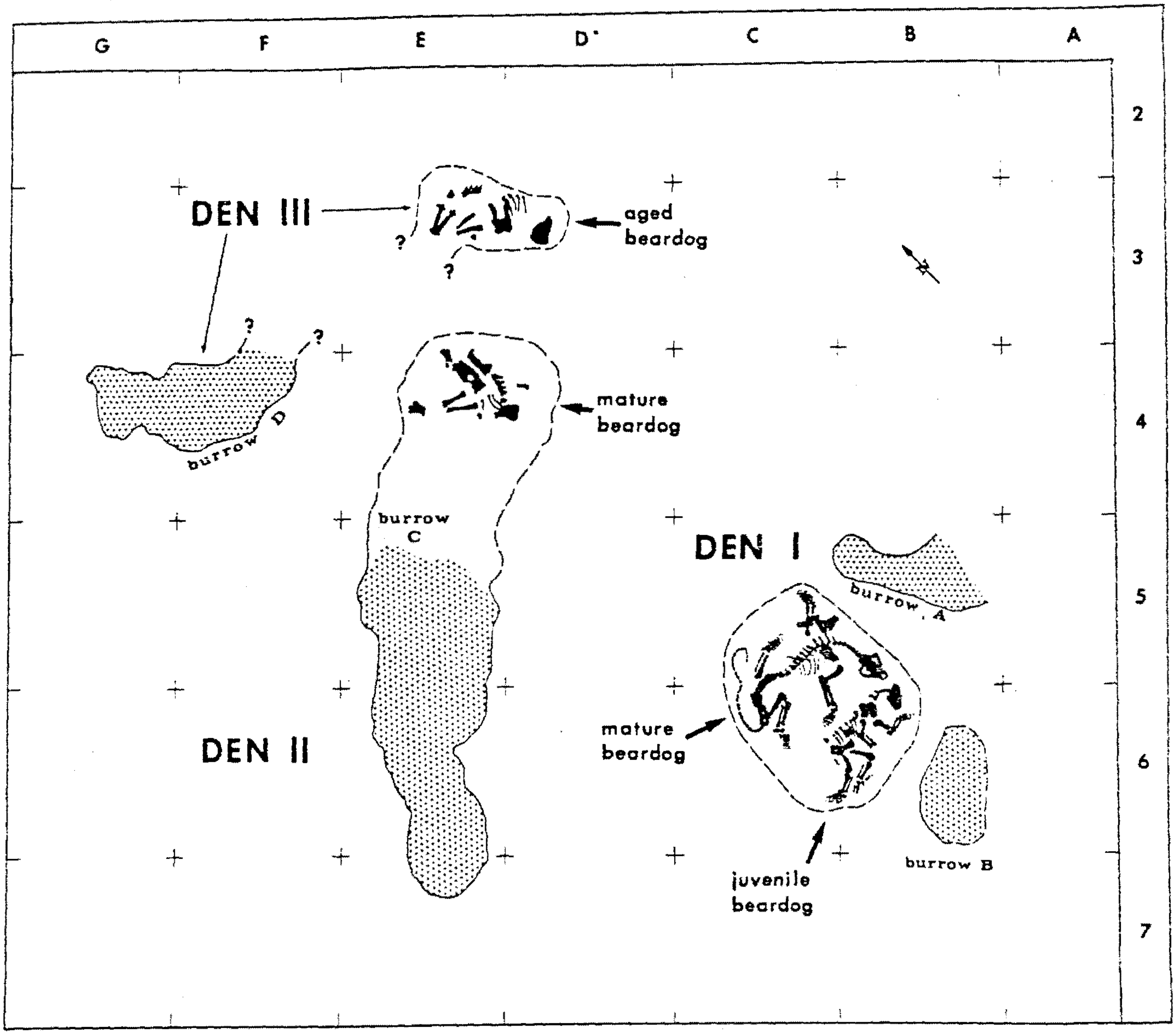
MAP H



American Museum Chalicothere Quarry (Southwest Excavation)

Albert Thomson Map (1912 - 1916)

University of Nebraska Map (1981 - 1983)



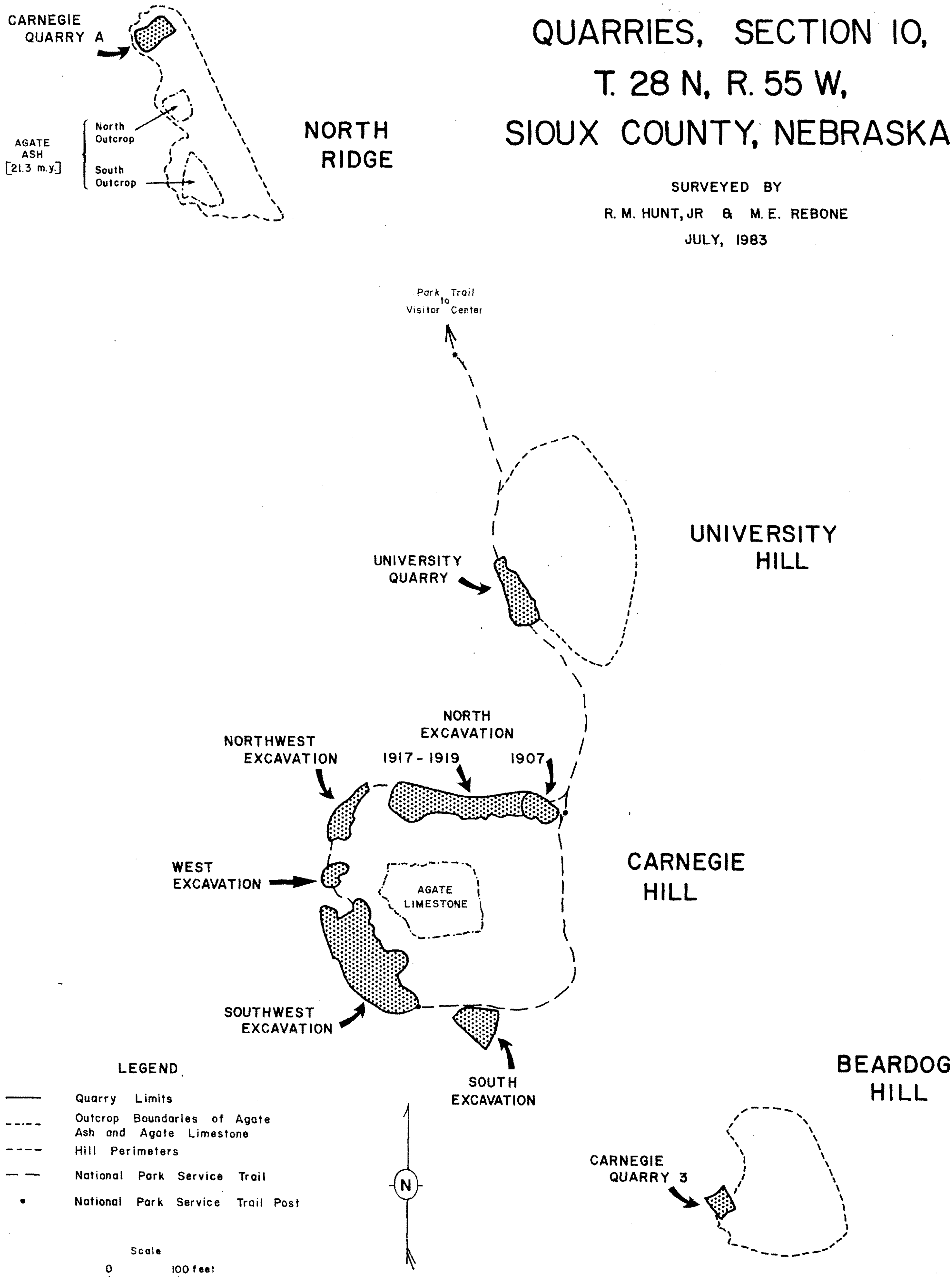
Plan map of early Miocene carnivore dens, Beardog Hill, Agate National Monument. Excavation grid is in square meters. Stipple pattern indicates intact burrow fill of gray ash-rich laminated fine sand. Burrow fill also surrounds skeletons but has not been shown for clarity. Dashed lines mark estimated den boundaries based on current excavations. O.A. Peterson discovered an adult female beardog and a juvenile male belonging to the species Daphoenodon superbus, probably in Den I. The University of Nebraska party from 1981 to 1983 found an aged individual of Daphoenodon superbus in Den III, and a mature young adult beardog belonging to a rare unnamed species in Den II. In addition, remains of a large mustelid and small canids have been found in the quarry, presumably former den occupants. Almost nothing but carnivore bones have been found in Carnegie Quarry 3, and all bones encountered by the University of Nebraska party occurred within the burrows. Recently, in October 1983, a new den was found northwest of burrow D. The Quarry 3 burrow complex is the oldest record of denning behavior by large mammalian carnivores yet discovered.

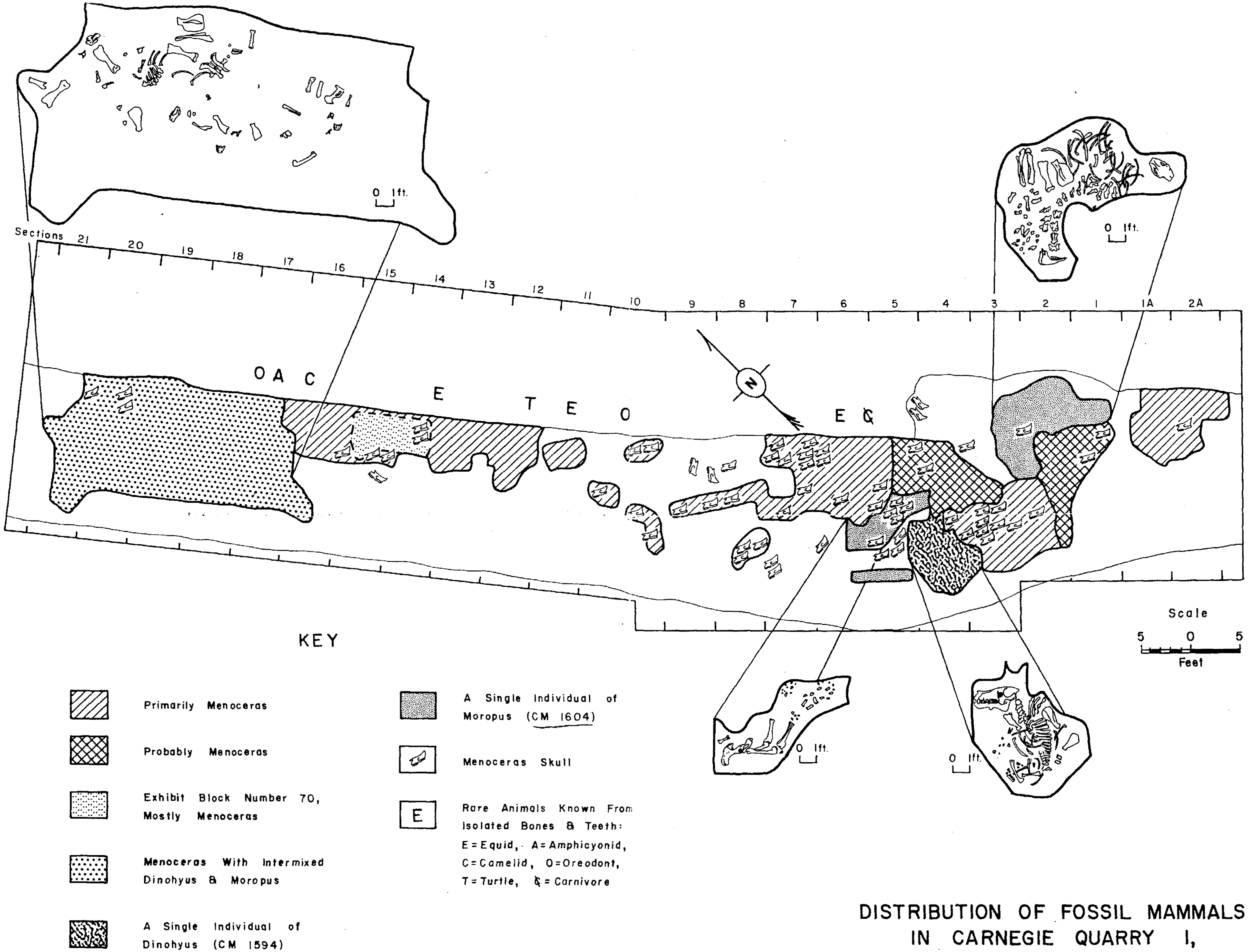
MAP OF THE AGATE SPRING QUARRIES, SECTION 10, T. 28 N, R. 55 W, SIOUX COUNTY, NEBRASKA

SURVEYED BY

R. M. HUNT, JR & M. E. REBONE

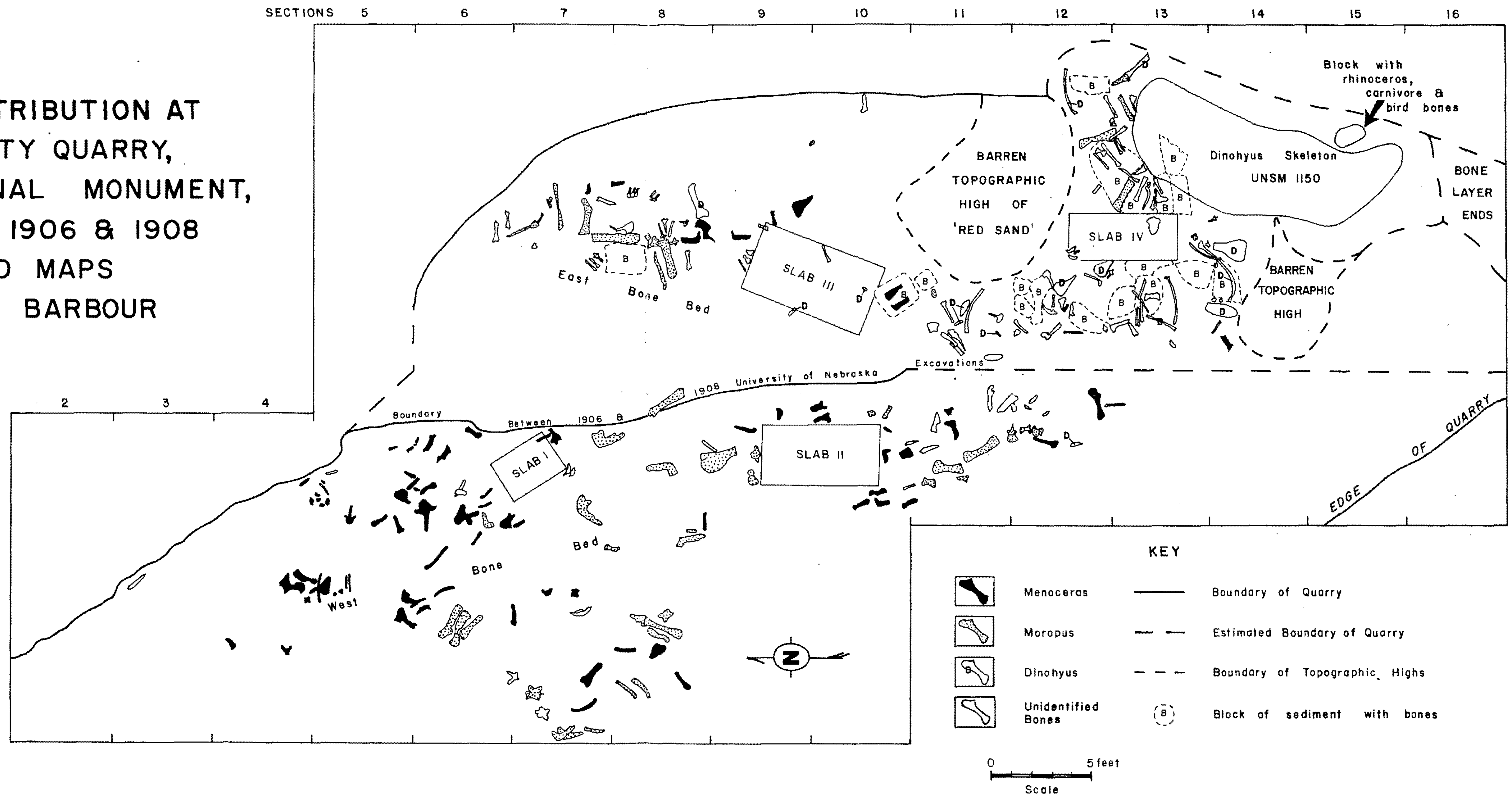
JULY, 1983

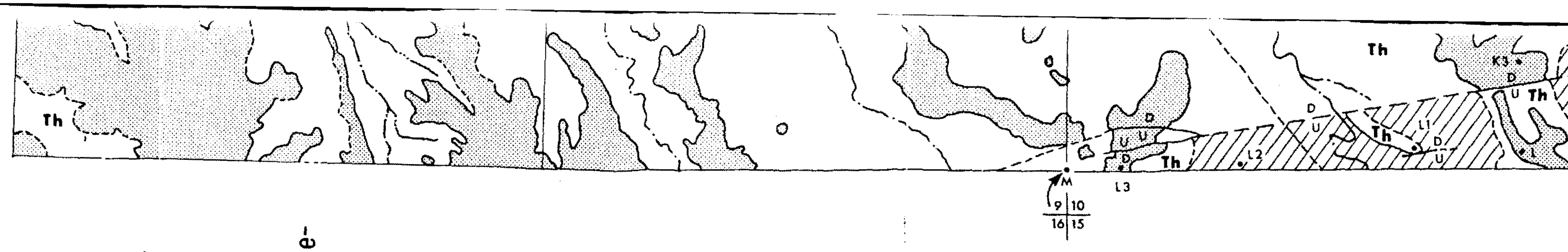




DISTRIBUTION OF FOSSIL MAMMALS
IN CARNEGIE QUARRY I,
CARNEGIE HILL
(SOUTHWEST EXCAVATION)
1904 - 1908

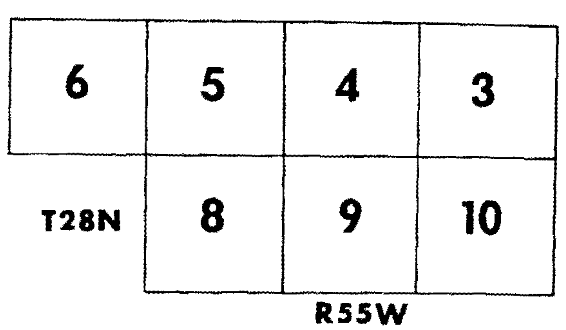
BONE DISTRIBUTION AT UNIVERSITY QUARRY, AGATE NATIONAL MONUMENT, BASED ON 1906 & 1908 FIELD MAPS OF E. H. BARBOUR





LEGEND

- Geologic contact (dashed where inferred)
- Intermittent stream
- Unimproved road
- • E4 Boundary marker (National Park Service)
- U/D Fault (dashed where inferred)
- ****** Agate Ash (KA 481), 21.3 m. y. B. P.
- Fossil quarry
- ▲ Windmill
- ■ Building or other structure
- Dam
- 9|10 / 16|15 Section corner (established by survey)
- R River access parking area
- ◆ Hole-in-the-Rock (Warren 1857 expedition)



Pleistocene-Recent

ALLUVIUM AND TERRACE — Silt, sand and gravel

Unconformity

Early Miocene

RUNNINGWATER FORMATION (Trw) — Nonmarine light buff to orange sand, massive, often with local zones of carbonate cementation, and occasional lenses of crystalline gravel, sand and silt of fluvial origin

Disconformity

UPPER HARRISON BEDS — Nonmarine light gray to light brown fine sand and silt of pyroclastic origin, massive in its upper part within the monument area, and in its lower part often reworked by fluvial and aeolian processes into horizontally laminated and cross-stratified deposits, with buff to white lenses rich in mammalian fossils filling the base of local channels. Includes local dense freshwater limestones (Agate Limestone), volcanic ash and lithic pebble conglomerate. In the study area the unit contains at or near its top a prominent silica-cemented land surface (Agate paleosurface) extensively burrowed and rich in root casts

Disconformity

HARRISON FORMATION (Th) — Nonmarine gray to dark gray fine sand of pyroclastic origin, massive, but locally reworked by fluvial and aeolian processes into horizontally laminated and cross-stratified deposits, and including throughout the monument the Agate Ash (KA 481)

Disconformity

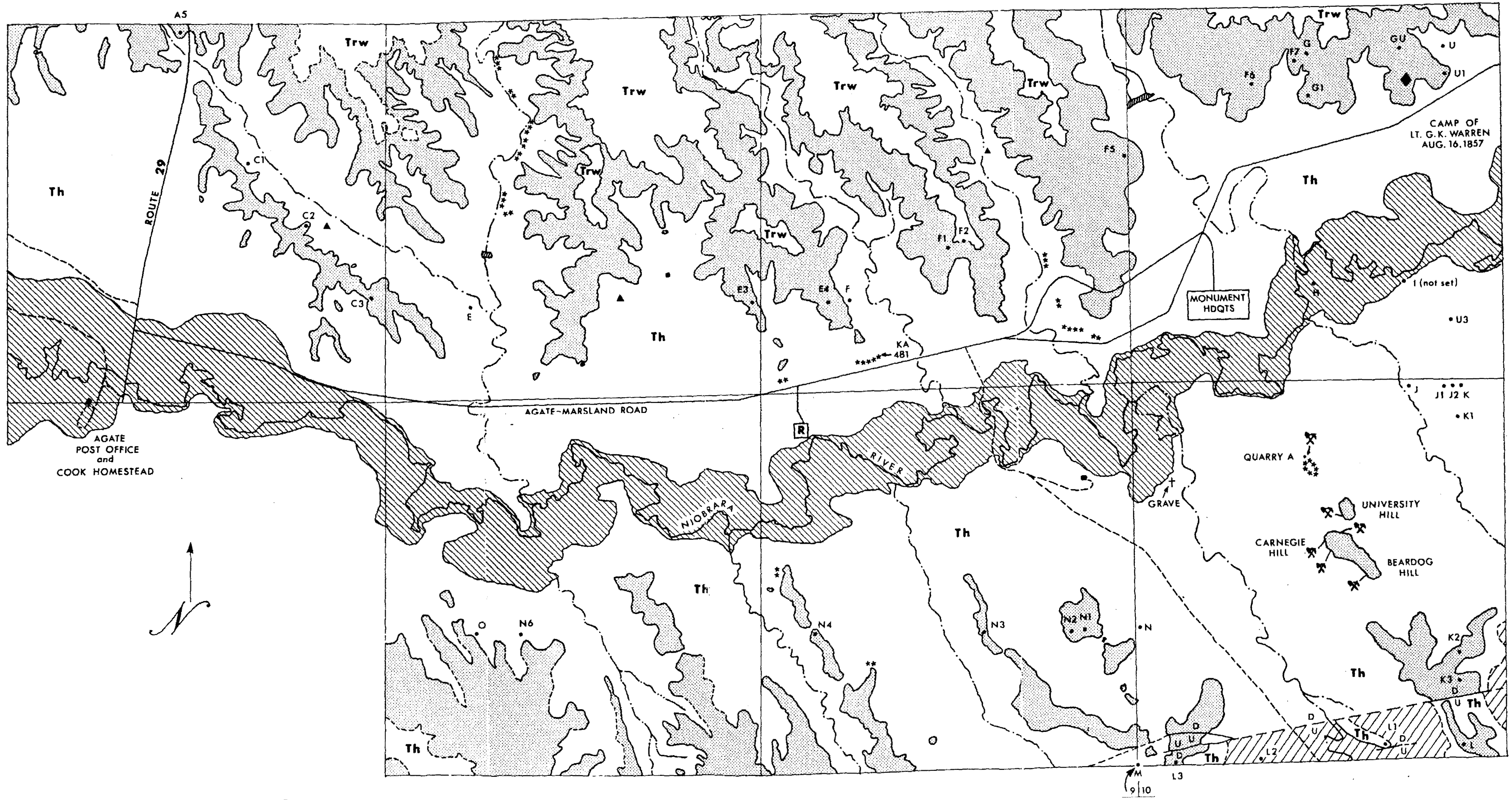
Oligocene?

UNNAMED LITHIC UNIT — Nonmarine light orange to light brown sand and silt of pyroclastic origin, massive, with frequent small vertically oriented carbonate concretions scattered throughout the unit

GEOLOGIC MAP OF THE AGATE FOSSIL BEDS NATIONAL MONUMENT

BY

Robert M. Hunt, Jr. (1977)



LEGEND