NATURAL HISTORY OF CENTRAL ASIA

VOLUME II

GEOLOGY OF MONGOLIA

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CENTRAL ASIATIC EXPEDITIONS

GEOLOGY OF MONGOLIA

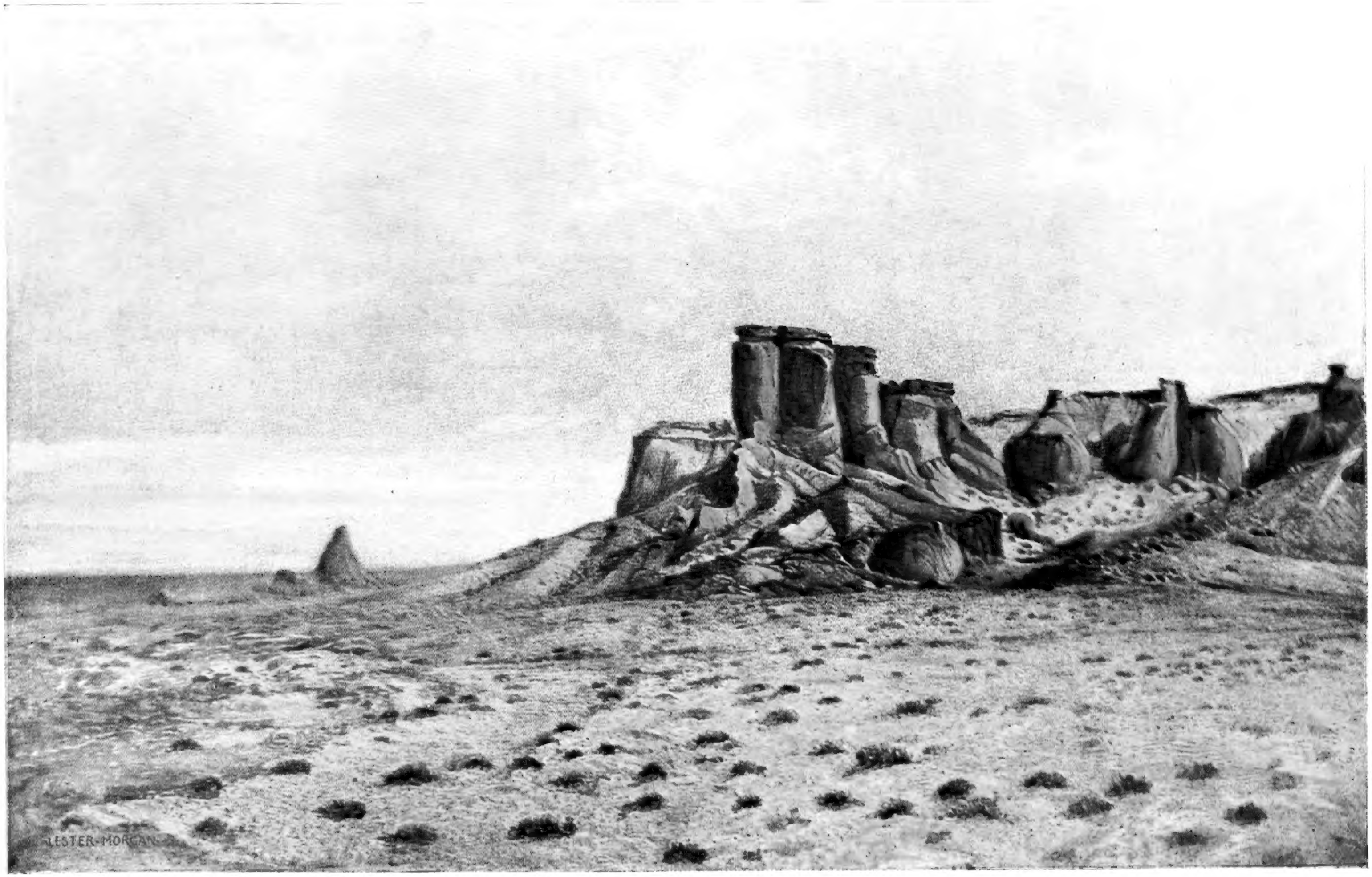
LESTER-MORGAN

Plate I.

THE FLAMING CLIFFS OF DJADOKHTA.

(Painted by C. Lester Morgan after field sketch in water color by Frederick K. Morris.)

CENTRAL ASIATIC EXPEDITIONS

ROY CHAPMAN ANDREWS, *Leader*

GEOLOGY OF MONGOLIA

A RECONNAISSANCE REPORT

BASED ON THE INVESTIGATIONS OF THE YEARS 1922–1923

BY

CHARLES P. BERKEY

CHIEF GEOLOGIST

PROFESSOR OF GEOLOGY, COLUMBIA UNIVERSITY

FREDERICK K. MORRIS

GEOLOGIST

AMERICAN MUSEUM OF NATURAL HISTORY

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NATURAL HISTORY OF CENTRAL ASIA

VOL. II

THE AMERICAN MUSEUM OF NATURAL HISTORY

HENRY FAIRFIELD OSBORN, *President*

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PREFACE

The series of volumes of which this one forms a part is intended to cover a wide range of investigations conducted by expeditions into Central Asia under the scientific supervision of the American Museum of Natural History. The Third Asiatic Expedition of 1922–23 was one of these, operating in Mongolia under the leadership of Roy Chapman Andrews, and the volume now presented grew out of the observations made at that time. The succeeding volumes will include investigations in all of the branches of science represented, and will cover the results of many years of field exploration and related study by different groups of men. The whole effort is directed to a better scientific understanding of the continent of Asia, especially its central and less readily accessible portions. Field observations and the collecting of material have already occupied several years, and the exploratory side of the work is still in progress. Doubtless it will take a much longer time to describe and interpret the collections and field notes.

This volume is devoted entirely to geology. It is confined to reconnaissance studies, especially the traverses of the Third Asiatic Expedition in the season, 1922, when both geologists were in the field together. The results were used in 1923 when the junior author had additional opportunity to revisit certain districts and see new ground. Since the manuscript of this volume was first written, the Expedition of 1925 gave further opportunity to both geologists to carry the investigations forward, but the results are not included in this volume. The reconnaissance observations of 1925, together with a series of special studies, are to form the next volume.

The traverses furnishing the material for this volume amount to about 5000 miles of travel in central Mongolia. Observations are distributed from the vicinity of Kalgan on the southeast, to Urga on the north, and, on the west, to Sain Noin in the Khangai Mountains and Baga Bogdo of the Altai Ranges. The area has been crossed and recrossed with little duplication of trails; nevertheless, there are wide spaces untouched and large areas whose geologic details are quite undetermined. The general geologic structure, however, has proved to be readable; the major units have been recognized so many times and at so many different places that it is believed the general geologic features and history are now reasonably well established. The area to which these studies apply amounts to not less than 200,000 square miles. It is an enormous area to cover in so short a time, and if it were not for a certain simplicity of geologic history the results could not be presented with any confidence. Doubtless an immense amount of detail will be added as the work proceeds, but it is believed that no large item in the geologic statement is likely to be greatly changed.

This reconnaissance is put forward as a step in the unraveling of the geology of Central Asia. We recognize its incompleteness and its many unsolved problems, yet we are confident that it is based upon true lines with respect to structure and historic succession, and that it ought to serve a useful purpose as a background for additional exploratory investigations.

Many problems have presented themselves as the work has proceeded. It is hoped that some of them may be given further study. Data already in hand bear on problems that have not been discussed in this report but are expected to yield results on laboratory investigation. There are yet other problems which cannot be solved except by additional field work of a detailed and extended nature. In so far as future work makes it possible, we hope to present these in succeeding volumes as opportunity may arise.

The four parts of this volume exhibit very different range and have different purposes.

Part I is essentially an introduction to the field and methods of work.

Part II covers the traverses and records observations along the route.

Part III includes a series of locality studies where more careful and detailed work could be done.

Part IV is an attempt to summarize in geologic terms the meaning of the mass of data assembled from these studies.

Readers not primarily concerned about the geological record will find certain portions of more general interest. To them we recommend the introductions under each Part as well as certain chapters in each Part, as illustrative of the nature of the investigations. Chapters I, III, XII, XIV, XXI and XXII present a series of pictures to the general reader, and we commend them as of broad enough interest to be of service to the layman.

We are indebted to many organizations and many more individuals for helpful suggestions and for assistance in assembling and presenting this work. Due recognition is given some of them in the body of the report.

To the generous friends of scientific exploration who have contributed the funds that have made this work possible we owe a special debt of grati-

tude. Without their support neither the field investigations nor the subsequent research could have been carried out. The sponsors have also borne the expense of publication; thus enabling the Museum to offer the volume at cost. Their interest in pure science and their faith in this venture have helped to materialize visions that otherwise must have vanished as they came, as many others before have vanished.

It is fitting that special mention should be made in this place of the helpful coöperation of the Geological Survey of China, and that we should acknowledge the interest of individual members of the staff, particularly Dr. V. K. Ting, former Director, and Dr. Wenhow Wong, the present Director. To Dr. A. W. Grabau, Chief Stratigrapher and Palæontologist, we have turned repeatedly for helpful suggestions. Dr. Grabau has undertaken the identification of the invertebrate fossils collected by the Expedition and will publish his results in a subsequent volume of this series.

In the preparation of this material for publication, still more vital assistance has been rendered by members of the staff of the American Museum of Natural History, whose close connection with the work of the Expedition has given special acquaintance with and insight into its scientific problems.

It is a pleasure to express special obligation to President Henry Fairfield Osborn whose prophetic vision is being fulfilled and whose guiding hand in these Asiatic explorations has been felt from the beginning.

We are deeply indebted to Acting Director George H. Sherwood on whose shoulders has fallen the home administration.

To Dr. W. D. Matthew, whose wide knowledge of palæontology and Cenozoic history make him an authority, we have referred many questions, particularly as to the correlation of a number of the Tertiary formations.

The heavy labor of editorial work has been borne by Dr. Chester A. Reeds, assisted by Miss C. M. Beale and Mrs. Mary V. Forster. It is an especial pleasure to record our gratitude to Dr. Reeds, whose constructive suggestions have been exceedingly helpful. Dr. E. W. Gudger has aided in the preparation of the bibliography.

Among the institutions whose services should be acknowledged is Columbia University, from whose faculty ranks the chief geologist came, on an assignment to field investigation. This service was rendered at a sacrifice made by the staff of the Department of Geology, since an absence of this kind thrust additional responsibility on every remaining member. Special recognition should be accorded to Professors James F. Kemp, Roy J. Colony, and Douglas W. Johnson, who together shared the chief burden left to the Department. Professor Johnson has read portions of the manuscript and has given generously the benefit of his keen and scholarly criticism. Contributions to such a piece of work, therefore, are made by many whose actual participation is not apparent, and it would have been much more difficult to carry it to completion without their help.

Professor V. A. Obruchev, of the Academy of Sciences at Moscow, has kindly contributed a list of references to Russian geological publications which proved a most helpful guide in reviewing the literature on Central Asia. Professor Obruchev has also aided in the preparation of the map showing the routes of Russian explorers (Plate II).

To Mrs. Florence Eddowes Morris, Mrs. Flora Cook Parks, Miss Helen R. Fairbanks, and Miss Agnes Molloy, we are indebted for valuable help on the manuscript. The illustrations are the work of many hands, some of which are acknowledged in the text. Messrs. Andrews, Granger, and Shackelford have furnished some of the photographs. Professor George B. Barbour, of Yenching University, Peking, contributed the photographs appearing as Plates VIII A, XLI A and B. Mr. Edward J. Alexander drafted the geologic cross-sections of the first ten chapters, chiefly from the field notebooks of the senior geologist; Mr. Erwin J. Raisz drafted the base maps, and Mr. Leon B. Hills made a number of the diagrams.

A place of highest honor for contributory service must be reserved for the members of the field staff of the Expedition with whom we worked day after day amid the privations and perplexities of strange and uncharted regions. With these men we endured the hardships that months of isolation always bring. With them we worked in surroundings of seemingly boundless desolation where only the unaccountable enthusiasm of the explorer, or the zeal of the scientific investigator, or the lure of the confirmed wanderer could have made the drudgery of those days appear to be worth what it cost. With their coöperation and encouragement the secrets of the desert were slowly searched out. And, now that we can look back on those toilsome days that stretched out almost endlessly month after month, with never a glimmer from the outside world, and with self-appointed tasks that taxed endurance to the last dregs, all seems like an entrancing dream that slowly takes on the glamour of a golden age.

These men we came to know intimately and, as our problems were discussed together, we learned to rely on them for daily help and encouragement. Sympathetic and helpful companions they were through all the confusions and discouragements that in the nature of the case belong to the borders of the unknown. Their service cannot be measured. We can only say that we appreciate it all, and realize full well that except for their fine spirit of coöperation the results must have been very different indeed.

To the leader of the Expedition, Dr. Roy Chapman Andrews, whose humanness and sanity under disappointments and successes alike helped to stabilize what might have become an ineffective effort, is due a kind of credit unlike that of any other. Except for his genius the Expedition would never have been formed; except for his success in interesting public support and inspiring faith in the undertaking, the work could never have been kept going, and, except for his confident leadership and good fortune in the face of mountains of difficulty, calamity might easily have overtaken the venture.

To Walter Granger, Chief Palæontologist, whose patient quiet manner and scientific competence inspired general confidence, we owe another special acknowledgment. The work of the geologist and of the palæontologist interlock and overlap. Both use the same data. Some of the records that both search for in the field are to be found in the same strata, and the history that both strive to unravel is closely interwoven. Their stories supplement each other. Their discoveries are often made together or are made one for the other and must be freely contributed to the general good. Therefore, it is vital to the success of both that the fullest coöperation and the frankest relations should be maintained. With such a man as Granger the task is easy.

To J. B. Shackelford, the photographer, whose artistic work speaks for itself, we owe an equal debt for other qualities. His ingenuity and practical knowledge in lines quite beyond his own special field made him the general advisor of the camp, and his genial nature and wonderful gift of humor never failed.

During the field season of 1925, Major L. B. Roberts, assisted by Lieutenant F. B. Butler and Lieutenant H. O. Robinson, made a series of route maps from Kalgan to Orok Nor, about 865 miles. These maps will be published in a later volume of this series, but the altitudes, which were determined by means of a large Gurley transit, have been used to correct the aneroid readings of the earlier traverses covered in the present volume. The outline of Tsagan Nor (Plates XXIX and XXX) has been corrected also to agree with Major Roberts' special map of that lake.

Each member of the whole staff has his own special claim to recognition and acknowledgment. In a kind of work where the chauffeur of one day may become a discoverer the next, or where a camp helper of one season may develop into an efficient scientific aid the next, and where competence and reliability in any single task make for so much greater efficiency in the whole organization, it is not possible to single out every individual for his full share of credit. Sometimes even our lives were in the hands of our companions, and that may have been true more times than we knew. If Bayard Colgate, in charge of transportation, had been less efficient or less accommodating; if Merin, the leader of the caravan, had been incompetent or untrue; if the supporting staff had failed in any major service, the whole story of accomplishment must have been very different.

So we recall with gratitude and appreciation the services of F. A. Larsen, the interpreter, and of the native Mongol guides, Sirimpil, Bato, Aioshi, and Tserin; of Merin's caravaneers, Banjien, Bato, Okher, Otoburun, and Sanjarav; of Colgate's transportation staff, Wang Hung Ping and Ah Sah; of the taxidermists, Chi Shou Lun and Hsia Wen Chiang; of Granger's staff of collectors, George Olsen, Peter C. Kaisen, and Albert F. Johnson; and those men whose constancy in their daily service about the camp made our own work possible, Loh and his staff, Chang Kwei Mo, Hwei Hsiu Yen and Kan Ch'uen Pao.

There have been scores of others, of lesser influence only because of fewer opportunities, but whose interest has been keen and whose sympathetic support and encouragement have been a spur to such accomplishment as is represented. We do not forget the importance of their service although it is not practicable to enter here all of the names that might properly claim a place.

To them all we offer this tribute of appreciation. That one of our number deserves most credit who executed his own task the best and thereby helped to make the whole interdependent organization so much the more efficient. Such results as have been attained in any field are only in part the simple product of the individuals directly responsible; in much larger part than is readily indicated they are a joint accomplishment. This is true also of the two authors of this volume. The interpretations here presented have grown up under continuous unreserved coöperative contribution of observation, interpretative understanding and experience. Certain parts of the volume took form originally as individual contributions, but all have been subjected to drastic revision by both authors. The work has grown in our hands so gradually and under such intimate discussion, and has been modified so many times that we ourselves are not able to separate clearly the elements that belong to each. The actual labor of preparation has fallen most heavily on the junior author; in the field, the larger experience of the senior author may have counted more heavily in coördinating and interpreting observations; but the result as presented is a joint product on which we have agreed, both as to form and substance.

CHARLES P. BERKEY,
FREDERICK K. MORRIS,
Geologists.

NEW YORK CITY,
October 25, 1926.

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CHAPTER I

GEOLOGICAL OBJECTIVES AND METHODS OF THE EXPEDITION, WITH A REVIEW OF FORMER EXPLORATIONS

INTRODUCTION

THIS volume is confined to the geological reconnaissance of the seasons of 1922 and 1923. In it are recorded observations made in the course of an extended itinerary across the desert regions of Mongolia. The major traverses include the following:

1. From Kalgan to Urga, a distance of six hundred and seventy miles, through Wan Ch'uan Hsien Pass over the Pacific divide, across the Gobi basin to the Arctic slopes of the Tola River region.
2. From Urga southwestward along the Tola River, through the Tsetsenwan district across the Ongin Gol, a distance of four hundred miles, to Sain Noin Khan on the Arctic divide.
3. From Sain Noin southwestward and southward three hundred miles to Tsagan Nor at the base of Baga Bogdo, one of the Altai mountain ranges.
4. From Tsagan Nor in the basin at the foot of Baga Bogdo, a hundred miles and more eastward to the Artsa Bogdo and Gurbun Saikhan ranges.
5. From the Gurbun Saikhan northward across the desert to the Sair Usu Trail, returning on that trail six hundred miles to Kalgan.

These traverses, together with side trips from certain base camps, gave an itinerary of more than three thousand miles—most of it in desert or semi-desert country, part of it in the mountainous country of the Arctic divide, and a much smaller part in the isolated mountain groups of the easternmost ranges of the Altai mountain system. Our traverses reached the center of the great continent of Asia, which in all probability has been inhabited by man longer than any other continent. Across its immense areas of desert and steppe country, caravans have journeyed from the time commercial intercourse developed between peoples, and travelers have toiled over these stretches of sand in the Gobi ever since man began to wonder about the earth and its possibilities. Here are the oldest trails of the world. Some of them are primitive transcontinental highways made by the tread of countless bare and padded feet, and dating back, perhaps, to the time of the great racial migrations.

Notwithstanding such a history, surprisingly little had been learned about the content and the meaning of the underground of the Gobi region. But as students of science continued to gather data of other regions of the earth, especially those facts bearing on early man and the animal life that preceded him, the conviction grew that Asia must have seen the evolution of man, and may have seen as much of many other races of living things. The race of man may have originated here; there was, however, no basis for a more authoritative statement, since no one had yet found much evidence in Asia itself, especially in central Asia.

It is surely not accident that has made the continent of Asia so important a factor in the development of man. Both man and beast have been more directly dependent on the corresponding growth and behavior of the earth than has been generally assumed. Geologic environment,—the whole physical setting of the past while this great continent was in the making,—may have been a more important factor in producing interrelated floras, faunas, races, and cultures of the present day than is fully appreciated.

Geologic history and the history of life run side by side, and have been intertwined and interlocked from the beginning; yet they are not equally dependent one on the other, for life is always subject to the geologic setting, and to some degree is compelled to adjust itself to the endless changes that the surface of the earth presents. Too seldom have geology and evolution been studied together as complementary parts of the same story. Thus these geological explorations in Asia take on a special significance, for the unraveling of whatever story there is to be told should give a better understanding of the long eras through which life progress has been made.

Some such considerations as these were in the minds of the sponsors and of the scientific staff of the Third Asiatic Expedition, and served to give direction and character to their undertaking. The general itinerary was chosen because the region which it covered appeared to have been touched by geological exploration less than any other of similar extent in central Asia, but it was modified in accordance with the problems that arose as the work progressed. The major traverse was projected across the Gobi basin with the conviction that somewhere in this basin country a series of sediments ought to have been preserved, which could contribute important facts to a better understanding of the geologic evolution of Asia, and of the development of present life forms.

The Expedition hoped to establish a better foundation for the study of all forms of life in late geologic time. It was, therefore, in large part, an expedition devoted to the unraveling of geologic and palæontologic history as recorded in the rocks of the desert regions of central Asia.

It had been predicted by Professor Henry Fairfield Osborn, many years before, that central Asia would one day yield important palæontologic contributions and perhaps connecting links in the chain of ancient forms of life, and that it would prove to have been a great center of origin for forms found in North America and Europe. It was not the province of the Expedition, however, to predict or to promise, but rather to investigate and to interpret.

Travelers crossing the desert seem to have found little support for these more or less speculative predictions, and the general reputation of the Gobi region was far from encouraging to such an undertaking as the Third Asiatic Expedition. It was evident, however, from the observations of such men as von Richthofen (1877) in the region farther south, and Obruchev (1900) in the Gobi proper, that there were sediments of somewhat uncertain age which ought to fulfil the requirements; but it took courage to project so expensive an expedition into a region apparently so desolate and unpromising as the Gobi. The region, to be sure, has been crossed by many other explorers, but with less advantage in operation and apparently with less success in detecting the elements of its complicated structure. In part this is because of the many natural difficulties that face the would-be investigator in such surroundings. Slow, tiresome travel; privation and occasional danger; heat, cold, and ceaseless winds; drifting sands and almost trackless wastes; scanty food and uncertain water-supply,—all these combine to make more complicated the task of an investigation whose uncertainties and puzzles are only one part of the practical problem.

It is quite outside our present purpose, and surely not necessary, to give a descriptive account of this now well-known Expedition. Its scientific staff was prepared to make every exertion to prove the quality of the enormous expanses of desert country in central Asia. The members were resolved to do as much as was humanly possible, on a hurried reconnaissance, toward interpreting the physiographic features and the geologic structure, the fossil content and the prospective palæontology of the region, and to determine, if possible, the significance of the processes represented in the rocks made in former times. They set out to discover and to read the story of the fossil remains that might lie buried in the strata. Whether any such finds could be made no one knew, but whatever contribution the country had to offer must be found. Geographer, palæontologist, geologist—together all bent their energy to one purpose. Each turned his best effort to unraveling that part of the story which was written in the language of his own science, from the present back to the beginning.

The major purpose was to see whether the Gobi region had fossil fields of late geologic time, to find how promising they might be, and to determine the structural and stratigraphic history of the plateau and basin country covered by Mongolia. In any case, whether the major object proved to be attainable or not, the staff of the Expedition was prepared to make a line of scientific determination across the northern desert, from China on the one side to Siberia on the other, so that it could be used as a standard for future reference and a guide to additional exploratory work. At least it should serve as a starting point for studies in other parts of the region.

As a step toward this end, a continuous cross-section, representing the geological changes and structure, was carried from the beginning to the end of the traverse. A good deal of ground was covered, of course, before much system could be discovered in the accumulating mass of data. In the course of time, however, a fair working basis was evolved, and certain localities were found to be of sufficient importance to deserve special and more extended study. At those places local, detailed investigations were made on a scale commensurate with their apparent geologic and palæontologic importance. These have become the key studies of the Expedition, and are supported by maps and large collections, both of rocks and of fossils.

In this manner there was constructed about three thousand miles of cross-section, part of it with accompanying route maps, and five special areas were given intensive study as local problems. Areal and structural reconnaissance maps were made, covering more than seven hundred square miles. At the same time, the physiographic features and processes of the desert were observed and studied, so that those features constitute an additional contribution. The maps of the region were entirely inadequate, and, therefore, attention was given to their correction, and to the more accurate location of important physical features or points of special interest.

The major results, in addition to the details of observation, include the following items:

1. Several great fossil fields of reptiles and mammals have been located.

2. The general geologic structure of the major rock formations of the Gobi basin region has been determined.

3. The major elements of geologic history of the Mongolian region have been unraveled, and a fairly complete geologic column has been worked out.

4. Extensive collections, both of fossils and of rocks, have been made, some of which are among the rarest and most valuable ever found in any region.

5. The principal steps in the physiographic development of central Mongolia have been detected in the features of the region.

6. A chain of scientific determinations has been welded between China on the one side and Siberia on the other.

7. The major problems deserving additional investigation have been indicated, and steps toward their solution have been suggested.

8. A great field for subsequent research has been opened in central Asia, which is certain to attract increasing attention in many other related sciences.

9. A series of special key studies has been made, to serve as starting points for future work.

In preliminary summary, it is, therefore, possible to say that, instead of being barren and hopeless, the Gobi Desert has proved to be one of the most productive geologic and palæontologic regions in the world. This volume records the observations and conclusions covering some of these results.

THE APPROACH TO MONGOLIA

The Expedition outfitted in Peking, and traveled inland by rail as far as Kalgan before taking to its own means of transportation. From that point motors were used for the scientific party, its immediate equipment and a few supplies. A caravan of seventy-five camels had been sent into the interior about two months in advance, with additional supplies sufficient for the whole season. After making connections with this caravan at Mount Tuerin, five hundred miles out, the movements of the two sections were coördinated in such a way as to keep the supply caravan within reach of the motor section.

This system of transportation and supply proved to be adequate during most of the season, and only an occasional side traverse or piece of local work had to depend on a different method. Rarely were supplies short. The several junction points were reached by the whole Expedition, and the movements of both sections were so well timed that no delay was caused by failure to coördinate.

Since it is not the purpose of this report to describe the incidents of the trip, or to cover the several other fields of investigation carried on at the same time, but instead to emphasize the geological observations, little further attention will be given in this volume to that side of the Expedition's operations.

The itinerary account will be carried without special reference to the method of travel, the incidents of camp life in the desert, or other happenings of the Expedition. These have been given in considerable detail by the leader of the Expedition, Roy Chapman Andrews, in semi-popular articles contributed to *Asia Magazine* and other publications (1922 to 1925).

Although the scientific work of the Expedition began beyond the outer walls of Kalgan, a better appreciation of the features first encountered there can be gathered from a statement of the geology along the route from Peking to Kalgan.

Peking stands not far from the inner border of the great alluvial plain of China formed by deposits carried by rivers that have come down from the mountainous interior of the continent. These alluvial deposits cover a complex erosion floor of older geologic formations (Fig. 1, page 8). The surface of the deposits is a smooth plain composed of gravel, sand, and silt, rising almost imperceptibly from the sea to a very abrupt and rugged inner margin which stands as a mountain wall nearly three thousand feet above the plain (Plate V, A, page 23). The Nan K'ou Pass pierces this barrier, and through it winds the old trail—northern China's principal gateway to the interior—over which seven centuries ago the Mongol hordes came on a very different mission. On a modern railroad that parallels the ancient trail to Kalgan, the Expedition set out to reach the heart of the country of the Mongols, which has become again a center of world interest, not because of anything the Mongols have done, but because of the remarkable geologic history of their vast desert region.

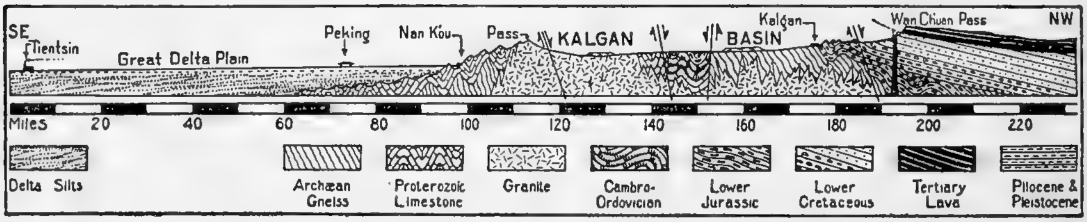


FIGURE 1.—Generalized geologic section from Tientsin to the Wan Ch'uan Hsien Pass. The section is intended to emphasize the step-like approach to the Gobi region from the great plain of northern China. The major underground geologic structures and the relations of the principal rock formations are indicated. They fall conveniently into three groups: (a) a simple delta, made of alluvial sands and clays built out into and displacing the ancient Yellow Sea; (b) a basement of complex rocks emerging from beneath the delta at Nan K'ou; (c) a cover of Mesozoic and Tertiary gravels, sands and clays with associated basaltic lava flows, beginning at Wan Ch'uan Hsien Pass.

In the Nan K'ou Pass, through which one must go to reach the higher lands of the interior, the older sedimentary rock formations come to the surface and are plainly exposed in all their complicated structure in the walls of the gorge. On entering the gorge, simple sedimentary strata are encountered, dipping southeastward beneath the plain. Then more complex formations appear in the core of the range. They are cut by large intrusions of granite, which continue to the upper reaches of the Pass. The geology of

Nan K'ou Pass is comparatively well known, and it is eminently fitting to turn to it as a key to help unlock the secrets of the ground that lies beyond. Many times in the course of the work the features of this pass were recalled, and the interpretations accepted for them were read into many of the rock structures of the interior.

On reaching the top of the Pass, however, one is surprised to see another plain, not very different in appearance from the one at the foot of the Pass, but this second plain stands at a much greater elevation, for it is not far below the crest of the mountain range (Fig. 3, page 42). The higher plain looks very similar to the lower one at Peking, but it lies between mountain ranges, is far smaller, and has a more variable floor and a much thinner cover of sedimentary strata. We may travel inland on this second level for many miles, but in due course we come again to mountain barriers that stand across the way, and if the interior is to be reached we must climb through other passes to yet higher levels.

Kalgan lies in a valley at the foot of these passes. It is located on the alluvial deposits of the Yang Ho, a stream whose variable flow cuts and fills and shifts enough at times to endanger the very foundations of the city. Occasional floods cause great damage and loss of life, for the inhabitants push their dwellings and tiny farms to the very edge of the river, on ground which may have been flooded only a year or two earlier. The trail to the famous Wan Ch'uan Hsien Pass climbs a tributary of this valley to the Pacific divide, and by way of it we may reach the edge of the plateau where Mongolia begins.

THE GOBI REGION

The Desert of Gobi occupies a broad, shallow, basin-like depression in the very extensive plateau of central Asia. From every side it is approached over a mountainous rim, and the trail stretches away for one thousand miles and more over desert and semi-desert country (Fig. 2). The monotony is broken by relief features which are chiefly the result of warping and uplift. Some of these features, like the Altai ranges, are of mountainous quality, for each one is a complex uplifted fault-block. Many of the ranges are rugged, and comparatively difficult to traverse. The less prominent hill-masses mark areas of gentler warping and smaller vertical displacement. Some of them are older fault-blocks that have been more completely worn down. Elsewhere the region stretches out in a succession of plains, marking the location of minor enclosed basins where down-warped areas have caught the sediments washed down from the uplifted segments (Fig. 10, page 53).

In spite of these irregularities, the average relief of the Gobi basin as a whole is remarkably slight. The basin measures six hundred miles in width, and more than one thousand miles in length, yet it is marked by an average depression of less than six feet to the mile—an amount not appreciable by ordinary methods of observation. For all essential purposes, then, the region is a great sweeping upland country, so many hundred miles in extent in every direction that one feels hopelessly lost in it.

FIGURE 2.—Two cross profiles of the Gobi basin. Both profiles are based on hundreds of systematically distributed aneroid readings. The vertical scale is exaggerated ten times.

Profile A crosses the whole of the eastern Gobi and shows a broad, shallow downwarp between the Arctic and Pacific divides.

Profile B crosses only the northwestern extension of the Gobi, lying north of the Altais, and shows much stronger warping and block-faulting than does the eastern section. Index letters are as follows: A D, Arctic Divide; S N, Sain Noin Khan; G, Gorida; U, Mount Uskuk; T N, Tsagan Nor; B B, Baga Bogdo.

In very early geologic time, the region had an entirely different physical habit from the present. Epochs of mountain-folding, of volcanism, and of great elevation and subsidence, with all their complexities of product and structure, have characterized the geologic history. In the beginning the region was mountainous and rugged, with rivers flowing in all directions to the surrounding seas (Fig. 153, page 367). After a very long period of erosion, the ancient continent was worn down almost to base-level, and the traces of this old peneplan are what one sees in some of the dissected remnants of the old rock floor. Since that time mountain-folding has not occurred there; but, under the influence of some of the inner forces of the earth, the whole region has been lifted and warped and faulted, so that the streams, which formerly carried sediments to the sea, turned inland and made deposits in the bottoms of the inland basins.

Ever since Lower Cretaceous time, when these changes came about, the region has been continental in habit. Centers of deposition shifted as new warpings took place, but deposits were nearly always being made somewhere, while in places deposits were being stripped from areas previously covered. The complete story of the later sediments of the Gobi region could be compiled by interpreting the data of all these basins. Bones of animals that roamed these plains from Cretaceous time to the present must be buried here and there in the deposits of the Gobi basins, and the story of the ancient life of the region, with its changes, could be written if their remains were found. Many epochs are unrecorded, so far as we know, and the continuity of the story is broken; but some of the gaps may be filled by future exploration.

If it were not for the fact that the story is more complex than the part of it already given, the complete history could not be unraveled. If the processes had stopped when the basins were filled with sediment, the history of the Gobi could not be worked out, because only the surface of the basin could be studied. However, since deposition began, there have been periods of deformation so pronounced in certain places that great series of sediments have been turned on edge and exposed by later erosion (Plate XI, A, page 61). Here one can measure each bed in detail and examine its content as successfully as though he had gone down through the whole series from top to bottom. In addition to this, there were, in former times, periods of greater rainfall than now, and streams have cut trenches into deposits already made. There are gorges and gulches, escarpments and uplands, where strata are exposed, in some places throughout considerable thickness, even down into the ancient rock floor itself (Fig. 11, page 54). At such places the meaning of the strata is legible, and ultimately a geologic column, covering nearly the whole depositional history, may be constructed by piecing together the data afforded by the various localities. A trial column, based chiefly upon the work of this Expedition, has been assembled, and will appear in Chapter XXII.

These are the obvious features of the Gobi region. The geologist soon learns their significance, so that the character of the country suggests the nature of the underground structure and something of its geologic possibilities. There is an alternating succession of broad, nearly level, smooth, gravelly plains which mark the presence of sediments, separated by more rugged areas of the uplifted and dissected hard-rock floor. Occasionally a characteristic dissection of the sediments themselves actually opens to observation the edges of the strata, and these alone are favorable for fossil collecting (Plate I). They are the great fossil fields of Mongolia.

Caravan trails reach out bewilderingly across this apparently endless country, intersected in a confusion of possible courses by the trails of herds and flocks and wild animals. Across such an open plains country, where tireless winds sweep the shifting sands, which are the only mantle obscuring the rock floor beneath, one must find his way and determine the geological structure, unravel the history of the region, and locate the fossil fields. Each day's traverse looks so much like the last in general surface features and landmarks that the traveler feels hopelessly lost; yet every trail leads somewhere, for these highways of the desert have served for centuries as the only connecting threads between otherwise isolated centers of culture in central Asia.

A Mongol guide is immensely more useful than any existing map. Save for his instinct in finding the right trail out of hundreds of possible courses, or, failing that, except for the use of the compass almost as the mariner uses it, one would inevitably come to grief in the Desert of Gobi.

PREHISTORIC ADVENTURE

One of the amusing foibles of a dominant race is its belief that exploration begins when men of its own blood travel into a "new land"—disregarding the peoples who have made it their home for untold centuries. So Mongolia, which has been a land of varying climate, favorable enough at times to attract races, and then arid enough to drive them out again, seems to have been forever under exploration. Before men lived in Mongolia, race after race of other creatures surged through the land and died in its broad basins, where we are now deciphering their history.

The tale of early human exploration will make a fascinating chapter when increasing knowledge enables us to piece it together. As we tell it now, the story is incomplete. Yet it seems advisable to fit the fragmentary evidence together as best we can, even though it will be many times corrected and added to as knowledge increases. We believe that future studies will confirm the inference that ever since there were men in Mongolia, their tale has been one of tribal migrations. As in Europe, clan after clan has entered this region and driven out or absorbed the earlier inhabitants. As their numbers grew, streams of nomad wayfarers went out to other lands. Each invasion brought new blood into Mongolia, and the new conquerors were in turn lured forth by rumors of better lands or were absorbed by the next immigrant horde, just as fate, climatic changes, and the laws of inheritance ruled.

History does not begin with the written page. Records are also made by bones, chipped flints, and ash heaps of vanished settlements, and are as much a part of human history as the Bible and the Rosetta Stone.

The earliest record is a single tooth obtained from a Chinese apothecary by Haberer (1903, page 20), and described by Dr. Max Schlosser, who reported on his suggestive discovery in 1903. It is not wholly certain that the tooth belonged to a human being; Dr. Schlosser claims only that it belonged to an anthropoid which was structurally nearer to man than any known ape. Clinging in the roots of this tooth is a bit of red clay. These are the only facts, and speculation upon them should be made with caution. No one knows where the tooth was found, or from what geologic horizon it came, but its primitive character suggests that it belonged to one of the earliest inhabitants of central Asia. We can only hope that future discoveries will throw more light upon this interesting problem.

The second chapter in the history of human adventure in Asia lies quite outside our region. In 1892, Professor Dubois (1894) discovered in Java the remains of a primitive human being, or, as some scientists believe, a creature rather more primitive than man, to which he gave the name *Pithecanthropus erectus*. The age of the beds in which the bones were found is generally considered to be early Pleistocene. No one knows how widely this early Javanese roamed, but it seems unlikely that the same species lived in both Java and central Asia.

The next cultural stages in the history of the region are much more definite and understandable. They are represented by a Palæolithic culture discovered in the Ordos by the distinguished explorers Père Emil Licent (1925) and Père Teilhard de Chardin (1924 *b*), and one Palæolithic and two Neolithic stages found in the Gobi by our own Expedition. Licent and Teilhard found primitive stone implements, not unlike those used by the Neanderthal man of Europe, and bones of extinct animals in gravels which were laid down before the vast deposits of "loess" were formed in northern China —probably in the Middle or Lower Pleistocene. Of the three stages found by the Third Asiatic Expedition, the palæoliths are apparently much like those of the Mousterian culture in Europe, but similar implements need not imply the same or closely related races or even the same period. These studies are as yet so incomplete that all we dare to say is that several stone-age civilizations existed in Mongolia long ago, and it is reasonable to think that they represent many successive invasions of the land by tribes which brought much of their culture with them.

Dr. J. G. Andersson (1923 *b*, *c*, and 1925) described an ancient Eneolithic culture in China that antedates all written and traditional records of the Chinese. Excellent pottery, ornaments and implements were made, but no metals were found in any of the old dwelling-sites. The material includes vases, plates and ornaments, with patterns so closely related to those of later Chinese art that he believes that the ancient culture was indeed Chinese. Dr. Davidson Black has examined the human bones which Andersson collected, and concludes that they belong to a people essentially similar to the present-day North Chinese (1925 *b*, page 98). Therefore the Chinese people probably had occupied China and had developed the elements of their civilization at least several thousand years before the beginning of their written history. They may have been invaders, too, but not even in their legends do we find the myth of an original homeland.

In many parts of Mongolia, especially in the north, there are stone monuments of many different types, built by races which were in the land before the coming of the Mongols. The Encyclopædia Britannica, quoting Radlov, says that the earliest inhabitants of this northern region were Yeniseians; remnants of these tribes still linger in the mountain-country of Uriankhai. They were succeeded in possession of the land by the Urgo-Samoyeds, immigrant tribes, who brought a finer art in gold, silver, and bronze than the land had known before. The Huns drove out these less warlike people about the third century B.C. The succeeding centuries were periods of vast tribal movements, and we hear of the Huns invading India on the one hand and Europe on the other—lured by the hope of better lands than central Asia afforded. Some of the monuments can be traced to the Turkish tribes which appeared in the fifth and sixth centuries A.D. They were masters of much of northern Mongolia and southern Siberia, but they were overcome in turn by the rising might of the Mongol empire which Jenghiz Khan built up in the thirteenth century. Gradually the Turkish tribes shifted away from Mongolia, or merged with the overwhelming Mongol peoples. As the power of the short-lived Mongol empire declined, the Chinese conquered Mongolia, and made it one of the "outer provinces." At about the same time, the Russian peoples were beginning to turn their eyes eastward to the vast lands beyond the Ural Mountains.

This sketch of man's ancient migrations in central Asia is dim and fragmentary, yet we think that it contains the first lines of a splendid picture which future studies may enable someone to paint in full color. We discern two parts in the composition of this picture: the older part, which deals with man's origin and descent, is but faintly sketched; the other part is a picture of migrating tribes and changing cultures, rather than the history of an evolving race. The first part reaches back into Pliocene and earlier periods; the second begins with the Ice Age, and continues to the present. Ancient adventure and the discovery of central Asia by successive migrating tribes constitute good subject matter for future scientific study.

HISTORIC TRAVEL AND MODERN EXPLORATION

Exploration implies travel for the purpose of collecting data of one kind or another. Travel for adventure and to satisfy one's urge for a larger world is older than exploration. The list of travelers is legion, but only a few names, chiefly of those who have made extensive traverses in the interior of Asia, may be mentioned here. Exploration proper is of very recent development, and scientific exploration in central Asia dates only from "day before yesterday," with a very short list of names. Among the travelers, Marco Polo is the dominant figure; among the explorers, von Richthofen is one of the earliest and most illustrious.

As early as 1253, Saint Louis sent William of Rubrouck to Mongolia to visit the court of Mangu, the grandson of Jenghiz Khan. William reached the court in the year in which Marco Polo was born. Fifteen years later, Marco with his father, Nicolo, and his uncle, Matteo, began the astonishing pilgrimages that were to fill his life and fire his only too active imagination (Yule translation, 1921). In the next century, Father Odoric traveled through Persia, India, and the East Indian islands to China, returning by way of Tibet.

These and other travelers brought back to mediæval Europe the earliest accounts of the Far East; but Marco Polo has given us the richest and most colorful picture of the land and people of Mongolia and China that was ever prepared before science came to guide exploration.

In the sixteenth century, at about the time when adventurous peoples from western Europe were beginning to colonize the new-found Americas, the Russians began to cross the Ural Mountains into Asia. We may picture two streams of migrating peoples, one pouring toward the west, the other toward the east: the one to cross the salt waste of the Atlantic to America, the other to traverse the tundras and swamps of western Siberia—the one to face the red Indian, the other the bronze Mongol. Each stream went forth to a pioneer's life, into a vast unconquered land, and each, despite the emphasis that written history lays upon wars, went armed rather with the plough than with the sword. Even the earliest records of Russian occupation of Siberia tell of farmers who were sent out with the soldiers: one group to build the blockhouse, the other to break the soil around it.

The ghastly story of exile and the prison camps of Siberia is one of those black chapters which no one palliates or defends. Most countries have tried the experiment of exile colonies in one form or another, and all have found, sooner or later, that it does not pay. Yet, curiously enough, one of the stories which concerns us in this book grew out of the prison camps of Siberia. After the battle of Poltava, in 1710, a Swedish officer named Philipp Johann von Strahlenberg was taken prisoner by the forces of Peter the Great. He was sent, with many others, to Siberia. During their long exile, Strahlenberg and his comrades studied peoples, languages, resources, and the geography and history of Siberia. With older maps to build upon, Strahlenberg made a new and astonishingly good map of Siberia, Turkestan, Mongolia, northern China and Tibet. An excellent critique of this map has been published by Sven Hedin (1917, I, pages 246–252) in his *Southern Tibet.* Two other prisoners of this same war, Schönstrom and Renat, made important geographical and ethnographical observations in Siberia, and Renat constructed a map of central Asia which gives the best picture of Dzungaria and the Tarim basin known up to that time.

Strahlenberg and Schönstrom bought from a Boucharan merchant a manuscript which they translated into several European languages. It proved to be a brilliant account of the Tatar or Mogul (Mongol) people, which was written by Abul Ghazi, prince of Khiva (translated 1729). The book is unfinished, for the writing was broken by the prince's death in 1663. He carries the history of the world rather rapidly from the creation of Adam to the rise of Jenghiz Khan, who was Adam's lineal descendant and Abul Ghazi's lineal ancestor. For a man who believed in magic and who dealt in traditional history, the work of Abul Ghazi is remarkably literal, and bears evidence on every page of an honest and scrupulous mind. Although we cannot include him among the explorers of Mongolia, his *Genealogical History of the Tatars* has become one of the source books for the history of the Mongol people.

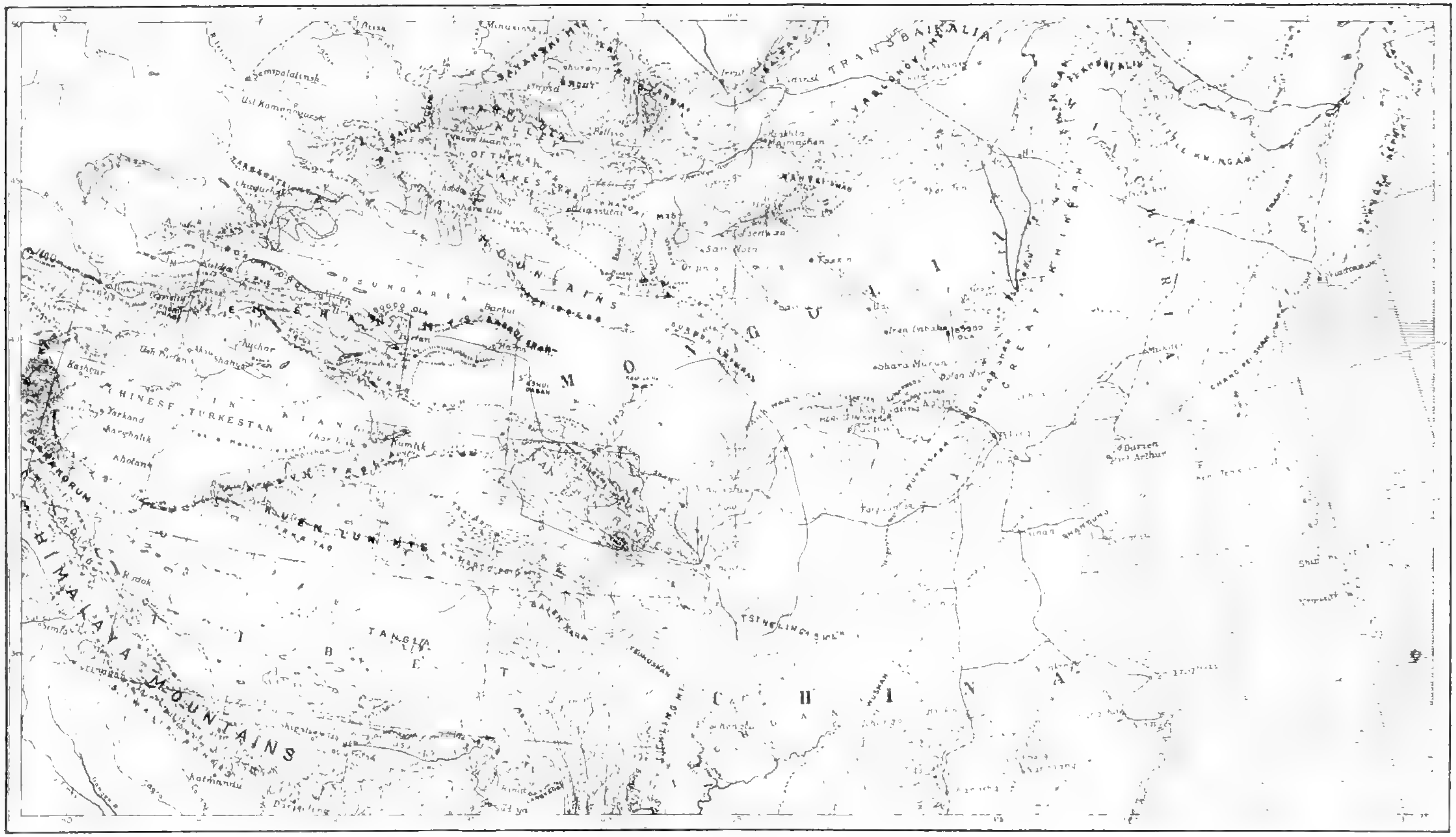
EARLIER STUDIES OF SPECIAL SIGNIFICANCE

Following the work of Strahlenberg, Schönstrom, and Renat, an epoch of scientific exploration of Siberia, Turkestan, and Mongolia opened. French, German, and Russian investigators searched out the resources of the vast region, studying its plants, animals, soils, rocks, and minerals. Naturally the work of the eighteenth century was crude and poor, and had to be done over again by the more fortunate and better trained scientists of the nineteenth century. A new era in the exploration of this region dawned in 1864, when an American geologist, Raphael Pumpelly, made the first geologic section across Mongolia from Kalgan to Urga (Plate III). In his short but excellent account (Pumpelly, 1866) he tells that Mongolia is an inland basin; that much of it is a plateau, or series of plateaus, formed of almost level strata of sandstone, clay, and lava sheets, interrupted by areas of granite and other massive rocks belonging to the oldrock floor; and that folded rocks, chiefly slates and schists, form another important structural element. This sane and simple analysis was the first great step toward the unraveling of the complex structure and history of Mongolia.

When Pumpelly crossed Mongolia in 1864, Ferdinand Freiherr von Richthofen (1877) had been two years at work upon his pioneer reconnaissance in the Far East. He examined the southern part of the great basin, and recognized the Khingan range as a continuation of the great line of flexure and faulting along which the mountains of Chihli bend down under the soft silts of the Great Plain. He noted the level strata of sand and clay, and called these beds the Han Hai Series. The name is Chinese and means the "dry sea." It is a beautifully figurative name for these immense and marvelously level wastes of desert above which the hard-rock hills rise like islands. But von Richthofen carried the analogy further, for he believed that these deposits had been laid down in an ancient sea.

Von Richthofen finished his researches in China in 1873, and was followed by the new school of Russian explorers. The character of their work changed from that of travelers to that of more scientific investigators. I. V. Mushketov (1876, 1906) had visited the Tien Shan while von Richthofen was yet in China, and, like the German pioneer, continued his travels for twelve years (Plate II). He noted the complexly folded rocks, cut by many kinds of once molten intrusives—granites, syenites, diorites, and porphyries. He collected

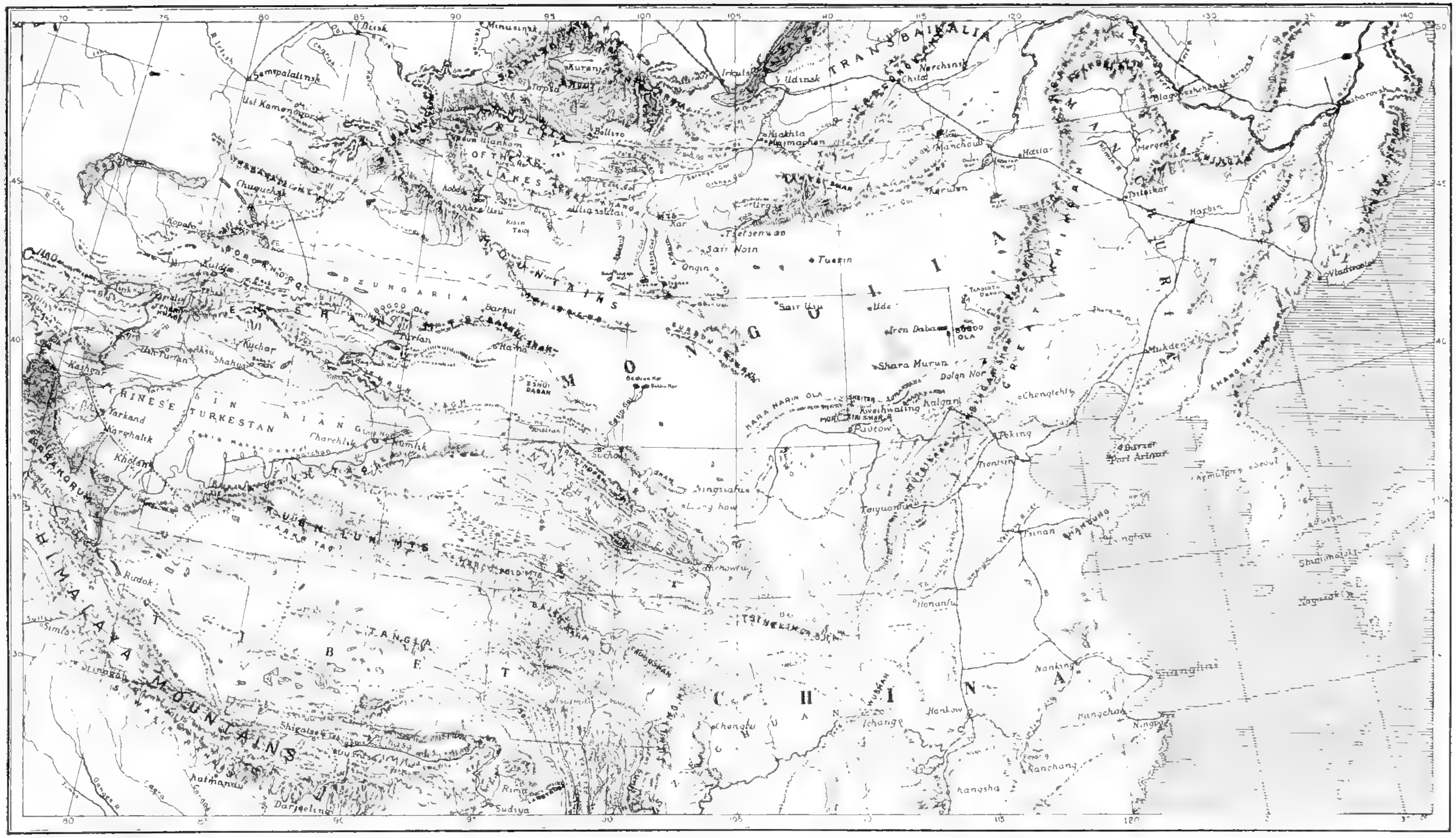
PLATE II.



MAP OF THE ROUTES OF THE RUSSIAN GEOLOGISTS IN CENTRAL ASIA.

Butin Brothers 1870
N M Prjevalsky, 1871-73, 76-77, 79-80, 84-85
H Fritsche, 1873-74, 77
. D Romanovsky IV Mushketov, 1874-75, 78 8
G N Potanin Expeditions 1876-77, 79, 84 85, 92-95
M V Pievtsov, 1876, 78-79
A Regel, [illegible]-77 78 79 82
Vanin, 1882
D A Klemenz, 1885-86, 91, 94-95, 98
K. Bogdanovich, M V. Pievtsov, V I Roborovsky 1888-90
V A Obruchev 1892-94
V I Roborovsky, P K Koslov 1893-95
P K Koslov, A N Kasnakov, V F Ladygin, 1899-1901
G N Potanin, 1899
M Friederichsen, Saposhnikov Expedition 1902
V A Obruchev, 1905-06 1909
A Chernov,– P K Koslov, 1907-08
M A Usov 1914
I P Tolstichin, 1914
Grum-Grshimailo brothers, 1889-91

PLATE III.



MAP OF THE ROUTES OF THE NON-RUSSIAN GEOLOGISTS IN CENTRAL ASIA

R Pumpelly, 1865.
L Lóczy, Count Széchenyi Exp 1878-80
Dutreuil de Rhins, 1890-95.
W.W. Rockhill, 1891-92.
Sven Hedin, 1894-1908.
Futterer Expedition, 1898-99
Aurel Stein, 1900-1915
A Tafel, Filchner Expedition, 1903. A Tafel, 1905-08
Pumpelly Expedition, 1903-04
W M Davis, 1904
E Huntington, 1905-06
Bouillan de Lacoste, 1908-09
P Gröber, Merzbacher Expedition 1908 09
D Carruthers, 1910-11
De Filippi Exp. 1913-1914.
Third Asiatic Expedition, 1922-23

fossils which told of Devonian, Carboniferous, and Cretaceous seas, and plant remains which recorded swamp-lands in the Triassic and Jurassic periods. He made a careful study of the coal in the Kuldsha basin, in Turkestan, and noted many other mineral resources. Romanovsky (1878) began exploring Turkestan rather later than did Mushketov; but the two pioneers joined hands to produce in 1884 a map of Turkestan which has been the foundation of all our scientific knowledge of that region.

Pievtsov and Bogdanovich (1892) traveled through eastern Turkestan, Dzungaria, Tibet and western Mongolia in 1889 and 1890. Bogdanovich (1892) made out the general geology of the region traversed, and laid the foundations for all later studies.

While the Russians were pushing their investigations outward from Siberia, the Hungarian count, Béla Széchenyi, undertook an extensive journey through China, southern Mongolia, and Tibet. He was accompanied by Gustav von Loczy (1893, 1899), who constructed a geologic cross-section throughout the entire course of the journey.

The explorations, which began in the west with Turkestan, were continued eastward by later investigators. It is not possible in a reconnaissance volume to do justice to the many colleagues who have contributed to this work through their writings, and the dry acknowledgments convey little of the appreciation due to the many deeds and thoughts of great summarists like Suess, and of master pioneers like Obruchev. The maps (Plates II and III) give some idea of the maze of routes traced across central Asia before us, but even this picture leaves much untold. We can give space to a very few outstanding names, and trust that in a later volume we may tell the whole story.

V. A. Obruchev, greatest of Russian explorers, began his travels in 1892 (1893). His advent marks a new era in the study of these great regions; the coming of a keener insight into geologic problems, with a better training in the science than that of any of his predecessors. He began, as was natural, where von Richthofen, Mushketov, Roborovsky, Bogdanovich, and others had left the story. He recognized at least two periods of mountain-building: an earlier, following the Permian period, when the strata were folded into ranges like the Appalachians; and a later, in Tertiary time after the earlier mountains were wholly worn away, when the land was broken along rifts, and tilted up as block-mountains (Obruchev, 1900, 1912, and 1923). Obruchev was the first geologist to discover vertebrate fossils in the Han Hai beds. His utmost care in collecting the fragments could not prevent their breaking still further; nevertheless, a tooth of general rhinocerotid type was pieced together, and was tentatively determined by Edouard Suess (1899) as a Rhinoceros or Aceratherium, which he believed to be of Miocene age. Obruchev's account of this discovery was in the hands of the geologists of the Expedition, and led them to pay special attention to this region, although, curiously enough, vertebrate fossils were found at two other horizons before the site of Obruchev's discovery was examined. In the northwestern corner of the Ordos, Obruchev found the skull of a fossil rhinoceros, probably of Pleistocene age, very near to the place where, more than thirty years afterward, the Jesuit Fathers Licent (1925) and Teilhard de Chardin (1924 *b*) made their great discovery of the implements of fossil man.

From the foregoing list of contributions, it is evident that a large number of exploratory investigations have been made in central Asia. The fundamental elements of the work accomplished have been taken as a ready-made foundation for the new investigation, and the original sources of a particularly helpful character require some additional comment and acknowledgment. These are: the contributions of Ferdinand von Richthofen (1877), and of V. A. Obruchev (1900); *Research in China*, by Bailey Willis (1907); and *Explorations in Turkestan*, by Raphael Pumpelly (1905). Each in his own field has penetrated an almost trackless wilderness of scientifically new territory, and has brought information and order out of difficult, obscure, and comparatively little-known regions.

The structural and stratigraphic elements of China, as given by Willis, furnished by all means the best starting point for the geologists of the Third Asiatic Expedition, because the work had to be projected from China as a base of operation. Furthermore, his work affords most direct and ready comparison, because, after the season's work, one returns again from the interior to the standard sections of China. We now know that a remarkable similarity of development is represented in the geology of the interior and that of the Chinese border. The two regions have approximately the same history. In past time they comprised a more uniform structural unit than the present physiographic differences suggest, so that the major structural features are essentially the same.

It is fortunate, therefore, that the Third Asiatic Expedition found it convenient to organize in China, as the staff was given special encouragement and help by the geologists of that country. It was of advantage, also, that one of the members of the geologic staff of the Expedition, Frederick K. Morris, had already accumulated considerable field experience in China and had become familiar with its formational and structural habit. Probably from no other base and under no other conditions could the work have been undertaken with so great advantage or so great likelihood of success.

It is certainly not advisable at this stage of the investigation to carry detailed correlation to such an extreme as to assume the identity of many of the individual formations in these two widely separated regions,—China proper and the interior desert plateau. Nevertheless it is true that the major structural units, as well as the principal deformation epochs and changes in the dominant processes, as marked out by Willis in China, can be recognized definitely, in the same order and with much the same proportions in the northern region.

The geological statement as given by Willis is, for another reason, particularly helpful. It not only recognizes formational units, but establishes them on a broad dynamic basis. Moreover, in describing them Willis manages to allow for expectable variations in the character and physical condition of the sediments, so that corresponding representatives or equivalents in new territory might be placed in the geologic column without serious revision. This is materially aided by a careful determination of igneous and deformation epochs, so that the whole geologic column is built up with suitable emphasis on the major breaks and the dominant forces or processes of each part. The Expedition came to appreciate the great service of such a contribution as this of Willis in China. One is the more impressed with its soundness after working, as this Expedition did, over several thousand miles of adjacent territory, where, again and again, this proved to be the only really helpful geologic guide.

In addition to the work of Willis in China, that of Pumpelly (1866, 1905), Davis (1904, 1905), and Huntington (1905 *a*, 1907 *a*), on the west side of the continent in Turkestan, ranks especially high in its applicability and helpfulness in a study of problems of the interior. For our region the geologic column representing the older formations, as given in the *Explorations in Turkestan*, is of little service; but the determinations bearing on physiographic changes, the significance of the processes and effects represented, and the order of events in later time are of far-reaching application on the continent of Asia. It would be strange, of course, if this were not so; for the men who participated are masters in their own fields, and their observations and conclusions could fail of wider application only in case the geological conditions were actually different. We now know that there is enough unity in the continent of Asia, despite its immense size, to enable us to correlate with reasonable success many important steps in its development, from China on the one side to Turkestan on the other.

The emphasis placed by the work in Turkestan on the changes that have taken place in late geologic time might be applied also in Mongolia, where the deformations, the processes, and the climatic changes are of similar type and of corresponding magnitude. The features are more easily read, are more definite, and are of greater significance in the desert region of the interior than in China proper. One finds, therefore, in the reports of these western explorations the clearest statement of the history of late geologic time, of the physiography, and of the processes that have made present conditions. The principles used and the explanations given were found to be a constant help in our studies of the interior, and we are confident that the summary given in this volume will be found to establish a reasonably consistent geologic link of field observation between these two justly famous investigations—that of Willis and Blackwelder in China, and that of Pumpelly, Davis and Huntington in Turkestan.

The most suggestive observations of the latter expedition are those which postulate a fluctuating climate, reaching back to the limits of human occupation and probably beyond; and those which establish the correlation of uplift and depression, with the shift of deposition centers during late Tertiary time.

Displacements of ten thousand feet, recognized by Huntington, are equaled in such movements as that of the Altai uplift of the desert interior; and the repeated warpings which Huntington refers to in similar connection are not only duplicated in many parts of Mongolia, but, because of the detailed determination of horizons in many adjacent basins, are established more firmly than ever before by the work of the Third Asiatic Expedition. By means of this work, epochs of deposition, of erosion, and of deformation have been dated and brought into definite sequence. Davis and Huntington in Turkestan recognized the significance of the evidence indicating these changes, and placed them for the first time, in their proper geologic and physiographic setting. The work of the Third Asiatic Expedition, while it supports the general conclusions of the expedition to Turkestan, attempts to go further in the definiteness of its correlations.

The work done in Siberia is more scattered, deals with more limited problems, and is difficult of access. Nevertheless, important observations have been made, and some of the conclusions derived from them are readily fitted to the Mongolian region.

CHAPTER II

BOUNDARIES OF THE GOBI REGION

INTRODUCTION

The Gobi Desert is merely the arid part of a great inland basin that lies enclosed between mountainous divides (Fig. 4, page 43). The highland borders of the basin are for the most part well watered grasslands that change by almost imperceptible gradations into the central desert. The boundaries of the desert proper are therefore not only indefinite, but inconstant, because a few rainy years extend the grassland, while a dry period makes the desert broader. The boundaries of the inland basin in which the desert of Gobi lies must be placed along the crests of the mountains that slope into the basin on the one hand, and outward toward the sea on the other. At first sight it seems as though the boundary would coincide with the watersheds which part the inland drainage from the waters that reach the sea, but this is not everywhere true, for the Kerulen River, after draining a part of the Gobi region, escapes to the sea through the Argun and Amur Rivers; and in the west, the Gobi is not bounded by marine drainage, but is separated by low, inconspicuous divides from other inland desert basins. In attempting to summarize the nature and structure of its boundaries, one has to rely largely upon a critical review of literature concerning the surrounding regions, and the record is very imperfect.

THE NORTHERN BOUNDARY

The northern boundary is everywhere mountainous, and may be divided into three general parts. The western part consists of the fault-block range called Tannu Ola, which connects with the Sailugem Mountains on the west, and, by several minor fault-blocks, with the Khangai uplift on the east. The central section includes the Khangai, Gangin Daba, and Kentai ranges, which may be considered as a series of arched or domed masses of complex rocks. The eastern section is formed of the Transbaikalian block-mountains which overlap one another obliquely along the Gobi basin, the southwestern end of each range plunging down beneath the Gobi sediments.

Northern boundary—western section

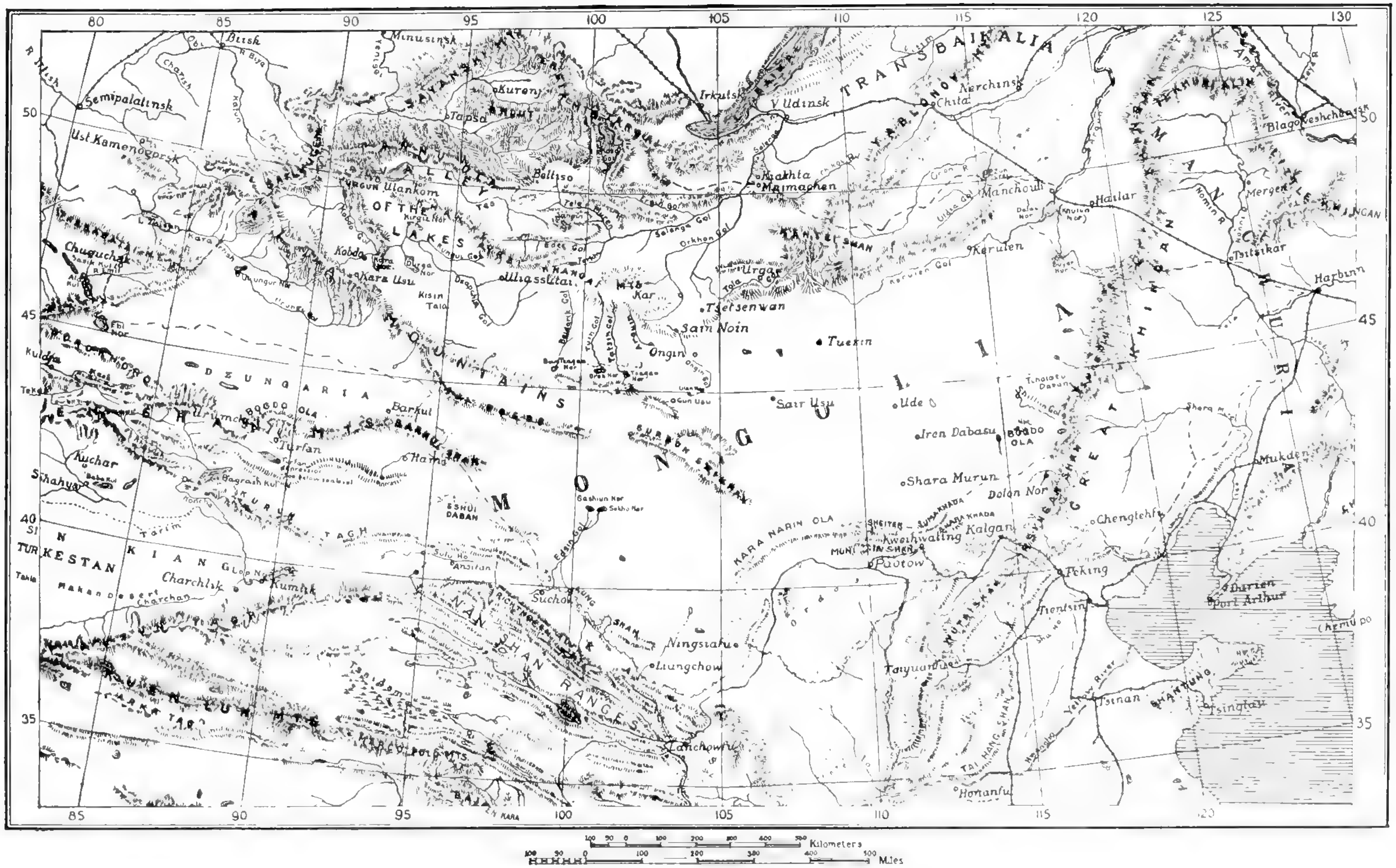
The northwesternmost part of the Gobi basin is a group of mountain-rimmed depressions called by Pievtsov the "Valley of the Lakes" (Plate IV). Its western wall is the Sailugem mountain chain, concerning which we have very little information. The northern rim of the Valley of the Lakes is formed by the Tannu Ola range, which is a stretch of the Arctic divide, parting the headwaters of the Yenisei on the north from the wholly enclosed Ubsa Nor basin on the south (Plate IV). The abrupt scarp of the Tannu Ola rising above the broad lake-basin strongly suggests that the range is faulted, forming as it were a shorter northern counterpart to the longer fault-block range of the Altai. Suess has assembled (1902, III, pages 111–117) three traverses of the Tannu Ola, and shows that the western traverse reveals only Devonian rocks—conglomerates, quartzites, and porphyries. The middle traverse brings in gneiss and granite, limestone, schists, marls, and sandstone. The sandstone beds contain plants belonging to the Carboniferous age (Culm). Just east of this section, on the north side of the range, the same traverse records Devonian strata, followed by Culm and then by the Jurassic Angara series. The third traverse begins on the north with the Jurassic Angara beds, and passes to the Devonian on the south side of the range. The rocks are folded and faulted.

Hausen, in 1917 and 1918, studied the part of the Tannu Ola lying east and west of the lake Kara Kul (1925). He reports that the rocks are largely igneous masses,—granite, grading into diorite and even gabbro,—which invade greenstones, limestones, and schists of uncertain age. Devonian sandstones and limestones with porphyries and lava sheets overlie the older rocks unconformably. The range is made up of several faulted blocks, and some of the longitudinal valleys, including that of the Kara Kul, are regarded as grabens. Hausen has thus shown that there are at least two ancient periods of folding, and that the folded structures of the mountain are broken by faulting of more recent date.

Northern boundary—central section

The Tannu Ola passes eastward into the general mass of the Khangai Mountains. The latter name is here used collectively for a mountainous region, rather than a range, lying between the Valley of the Lakes on the west and the Tola River on the east (Plate IV and Fig. 4). Suess says (1902, III, page 118), "Eastward the Khangai merges into the Kentai Shan and the mountainous regions north of Urga which are continuous with those of Trans-

PLATE IV.



LOCATION MAP OF THE BORDERS OF MONGOLIA.

PLATE V.

A. THE FIRST MOUNTAIN BARRIER. THE WESTERN HILLS FRONT NEAR PEKING.

B. THE GREAT WALL ABOVE NAN K'OU PASS.

This view was taken at Ch'ing Lung Chao, and shows the rugged crest of the first mountain barrier back of Peking. In ancient times this was the inner defense line for the great plain of China, the outer defense being the Great Wall above Kalgan, more than a hundred miles farther toward the interior of Asia. (See Plate XLIII B.)

baikalia. . . . No *tectonic* boundary separates the Gobi from the Khangai, since denuded remnants of a similar structure may be recognized in adjacent parts of the Gobi itself." Suess recognized horsts and grabens in the Gobi region, but as both the folding and the later faulting follow in general much the same structural trend, Suess did not clearly differentiate an age or ages of dominant folding from another age characterized by dominant faulting.

Tolstikhin (1920) made an extensive study in the region of the Selenga River in 1919 (Plate IV). We have not a copy of his paper, and must rely for the present upon Obruchev's review of it (1921, page 149). Tolstikhin noted a thick formation of steeply folded crystalline limestones, striking N. 30° W. to N. 50° W. and extending from the Kosso Gol to the river Telgir Merin (Plate IV). Northward from the river Murin, dolomitic limestones striking N.N.E. have been cut and metamorphosed by granites and granite porphyries. Associated with these limestones are quartzites, sandstones, and silicious schists, all of which Tolstikhin considers to be pre-Cambrian. He goes on to say that after a long erosion period, the region came again under water which covered the lower course of the rivers Murin, Buksui, and Eder and extended eastward along the Selenga to the mouth of the river Egin Gol. Gray and black limy clays and sands, with green and red sands and conglomerates, were deposited, in which obscure plant remains are found. This water sheet, he says, retreated toward northeast and east. While the sediments were being deposited, volcanoes poured out dark basic lavas and their tuffs. All of these rocks were folded at a later date, and strike W. N. W. to E. N. E. with dips less steep than those of the pre-Cambrian. The basic eruptive rocks were converted into green chloritic schists. Tolstikhin assigns these sediments and associated igneous rocks to the Jurassic Angara series of Suess. He describes a later granite-syenite intrusion, which closed with eruptions of keratophyre.

Obruchev (1921), commenting upon this paper, thinks it more likely that the later sediments may be not Jurassic, as Tolstikhin supposed, but possibly may be of Palæozoic age, citing his own discovery of Palæozoic bryozoans and corals between Urga and Kiakhta in rocks of much the same character as those observed by Tolstikhin. Obruchev considered it probable that "in northern Mongolia, as in the rest of Central Asia, except the region of Kashgar, the latest advance of the sea was in Upper Carboniferous or Lower Permian time" (1921, page 150). The possibility that these chloritic schists may be of pre-Palæozoic age should not be overlooked.

The route of the Expedition in 1922 led southwestward from Urga through a wide belt of the slates and graywackes. As this section is followed southward, igneous rocks appear, cutting the graywacke series, and increasing in number and size until the granite of the Mongolian bathylith is exposed over large areas, while the graywackes lie isolated as roof-pendants and xenoliths (Figs. 34 and 35, page 95). In the region of Tsetsenwan (Lat. 46° 15′ N., Long. 104° 10′ E.), the mountains are disposed in broad, relatively low blocks whose tops are beveled by an arched peneplane and whose fronts descend abruptly to basins with almost flat bottoms, some of which are floored by the granite, while others bear a cover of nearly horizontal sediments (Fig. 37, page 101). In the block-mountains we found in one place gneisses and marbles which we assigned to the Archæan complex; and in other places schists and crystalline limestones,—striking N. 75°–80° W. and dipping northward,—which we judged to be Proterozoic, comparable to the Wu T'ai series of China. They are all unconformably overlaid by the folded conglomerates, sandstones, and surface volcanic rocks which we tentatively consider to be Lower Jurassic. As we went northwestward again to Sain Noin, the graywackes reappeared. They form the entire region for many miles about Sain Noin Khan, save for infolded synclines of the Jurassic conglomerate. The graywackes are indeed present on a scale so vast that we called these rocks the Khangai series.

Thus the Khangai mountain region, taken as a whole, includes a great complex of folded sediments and igneous rocks, ranging from the Archæan to, possibly, the Lower Jurassic. Their upturned edges are beveled by a peneplane which forms the upland of the Khangai, standing as high as ten thousand feet above sea-level. All of these rock types were observed also in the Gobi desert, where they maintain the same folded structure and essentially the same strike as in the Khangai. The Gobi and the Khangai are not separated by a fault line or by an abrupt scarp, and Suess may have had this in mind when he wrote that there is no tectonic boundary between these two regions. The Khangai hills become lower, and extend in long tongues out into the desert; while the lowland of the desert surface extends up the valleys between the projecting spurs of the mountains. The mountain mass as a whole rises gradually above the desert and has the aspect of a broad dome in which faults and fault lines are not so conspicuously in control of the topography as they are in the Altai ranges to the southwest or in the Transbaikal ranges to the northeast. The streams heading on the two opposite sides of the Khangai watershed form a long dendritic drainage pattern which clearly suggests that the drainage is consequent upon the Khangai arch. There is no evidence in the river pattern of a former connection of the Gobi basin with the Arctic drainage. Along the Khangai front, however, the earth movements that have made the mountains were essentially a gentle doming or upwarping of ancient, complexly folded rocks which had been peneplaned prior to the uplift.

The Kentai Ola continues the Khangai northeast of Urga, and forms the Arctic divide in this region. J. Morgan Clements (1922) examined part of the Kentai hills, and expressed the belief that the graywacke series is of late pre-Cambrian age. Ussov (1915) reports in general an Archæan "Barchin Series" and an Algonkian graywacke series which are cut and metamorphosed by great intrusions of granodiorite. The Expedition in 1922 crossed the Gangin Daba Mountains, which may be considered the southwestern extension of the Kentai, and observed in the southern part a belt of schists, which we regarded as later than the Archæan, and probably of much the same age as the Wu T'ai system of Bailey Willis (1907, II, page 4). This correlation would not necessarily cast any doubt on Ussov's identification of Archæan rocks in the Kentai. Like the Khangai, the Kentai appears to rise gradually out of the great basin of the Gobi, without any marked tectonic boundary beyond a broad, gentle upwarp or doming.

Northern boundary—eastern section

Thus far the boundary of the Gobi has been placed along mountain crests that form the Arctic watershed. All water falling south of this divide runs southward into the desert, to escape only by evaporation. But the Kerulen River, heading in the Kentai hills, runs southward into the great basin of the Gobi, and then flows eastward nearly four hundred miles to the lake Dalai Nor, from which the waters escape to the ocean along the Argun and Amur Rivers (Fig. 4). The course of the Argun River follows the fault-graben along the eastern base of the Argun range to about latitude 50°, where it cuts across the mountain. Between this and the Khingan range the river follows some of the fault lines, and cuts across others. It swings around the northern end of the Khingan and joins with the Shilka River to form the Amur River (Fig. 4). The genetic origin of the Kerulen-Argun is an unsolved problem. The course is clearly a complex one, and shows two types of adjustment: along parts of the course the river is adjusted to the structure of the present ranges, and along other parts it cuts across these structures. If the mountains arose by faulting at somewhat diverse times, and at diverse rates of intermittent movement, a large river would maintain its course across the minor ridges, and especially across those whose growth was slow and of more recent beginning, while larger, older ranges and those whose increments of fault movement were greater, would force the river to take a course adjusted to the trend of the ranges. The Argun range has in part, and the Great Khingan has wholly, forced such adjustment to its own lines.

The mountains north of the Kerulen belong to the Transbaikal system of fault-blocks in which the rivers have a peculiar trellis pattern. Whether the topography is primarily controlled by block faulting, or whether the rivers have subsequent courses and have etched out their valleys along the weak zones of ancient fault lines, is another of the unsolved problems of the region.

Lvov (1916) says that the dominant topographic feature of the western Amur region is a group of short parallel-oriented massifs, separated from one another by narrow or broad, down-sunken depressions.

Obruchev (1899, pages 192–206, and 1926, page 432) has given a description of the broad features of Transbaikalia, in which he emphasizes the great width of the divides or mountain uplands, and also the great width of the valleys. He considers the mountains to be fault-blocks, and his map, which is redrawn and transliterated in Fig. 135, page 320, shows a long series of faults defining the present ranges. On the other hand, he does not throw direct light upon many important problems. He says that several ranges are "broken through" by rivers, but does not explain the origin of the river's present course. He stresses the fact that the ranges are bow-shaped, lying in arcs which are slightly convex toward the south; but he does not tell whether he believes that this shape is due to pressure or thrust from a given direction. He shows that the strike of the bedded crystalline rocks diverges in places quite markedly from that of the ranges. In the west, near Lake Baikal, the folded structure strikes east-southeast, while the faulted mountains lie east-northeast to northeast (Fig. 135, page 320). Farther east the prevailing strike is east-northeast, and here it falls into agreement with that of the mountains. Still farther east the strike of the beds is again east-southeast to southeast, and locally east-northeast, or northeast or even north, so that it lies now across, now diagonal to, and now parallel with the direction of the mountain ranges. Obruchev continues (1899, page 201):

> The Mesozoic and Tertiary rocks . . . in most cases strike parallel to the depressions, in which exclusively these rocks are found. It seems that they have been broken into larger and smaller tablets or plates, which sank steeply in this or that direction, and, locally, have thereby even formed shallow folds.

The post-Tertiary deposits are not dislocated.

Obruchev says (1899, page 202):

> The depositional relationships of the metamorphic schists, the Palæozoic, the Mesozoic and Tertiary rocks, show that the fault movements repeated themselves in later periods, and in general remained true to the first established strikes . . . Secondary horizontal movements accompanied the dominant vertical movements, as the folding of the sediments shows . . . The vertical movements of the earth's crust were accompanied by outbursts of massive rocks, which arose along fault-clefts. Many of these rocks pressed in as laccoliths into the Archæan masses, and have been laid bare only by later erosion and denudation. Elsewhere they form many dikes in the older rocks. But the existence and the wide distribution of tuffs, breccias and conglomerates which are associated with various porphyrites, mela-

phyres, trachytes, rhyolites, and basalts, and which in other places are interbedded and alternate with the ordinary clastic sediments, prove that many outbreaks reached the surface and that long chains of volcanoes were active along the faults at the margins of the ancient ("Archaische") horsts. The products of eruption came to rest partly on the dry land, and partly in the lakes, which occupied the valleys during many periods.

In the east in the district of Nerchinsk, the igneous rocks are as widely distributed as the crystalline schists and sedimentary strata; and in some localities the horsts consist only of the igneous rocks. Therefore the arrangement of the rocks in this district is not so regularly zoned as in the other parts of the region, and the structure is far more complex.

. . . Besides the dominant fault lines striking east-northeast, which mostly, even though with interruptions, have a great length, there are in the region other far shorter fault lines which run north-northwest to north. Such cross-faults, which in places appear to be connected with horizontal displacements, are seen in the west, but more especially in the district of Nerchinsk.

Obruchev says that these cross-faults are rudely parallel to the Khingan range, and therefore infers that they are related to the displacement history of the Khingan. He calls them the "Khingan faults" in contrast to the "Baikal faults" which lie parallel to Lake Baikal and form the prevailing mountain lines of Transbaikalia. He points out that the great Khingan range forms the eastern tectonic boundary of the Baikal region. At the western boundary is Lake Baikal, which Obruchev considers to be a great faulted depression, the deepest graben in Transbaikalia. Westward from this graben we meet with broad areas of Cambrian and Silurian marine deposits, which are relatively slightly dislocated. Here, then, very different rocks and very different tectonic relations dominate, so that Lake Baikal closes the western limit of the Transbaikalian fault lines.

"South and southwest of our region lies northern Mongolia, in which we find the same ancient metamorphic and massive rocks and the same tectonic lines as in Transbaikalia."

Summary of the Transbaikal border

As in the Khangai-Gobi contact, so also in the contact between the mountains of Transbaikalia and the great basin of the Gobi, there is no difference in the rock formations or in the lines of ancient folding. These facts point to the conclusion that the great basin of the Gobi is of more recent origin than any of the folded ranges. All of the folded mountains, including the Altaids of Suess, were wholly planed away before central Asia became an inland, undrained hollow. The present Gobi basin is relatively young, and was formed coincidentally with the uplift of the Transbaikal ranges. Both the Transbaikal mountain region and the basin of the Gobi were formed by deformation of a single great province of peneplaned ancient mountains.

THE EASTERN BOUNDARY

The eastern boundary of the great basin of Mongolia may be taken as the Ta Hsing An or Great Khingan range, which reaches from the Amur River at the north to the mountains of the Kalgan and Nan K'ou region in the south (Fig. 4). The Khingan range strikes about N. 25° E., and so lies athwart the structure of the Altai, Khangai, and the Transbaikalian mountains. The following brief account of this range is taken from the summary of Suess (1902, III, pages 117–122):

According to Gedroits, the northern part of the range has a width of one hundred eighty to two hundred versts, or about one hundred and twenty to one hundred and thirty miles. It is formed of igneous rocks and ancient schists, overlaid by deposits probably of the Palæozoic age, with intrusions of granite, porphyry, and diabase. Kropotkin (1865) and Manakin (1898) have recorded in Lat. 49° 30′ N., "clay-slate and granite and in places porphyry and upturned red sandstone" (Suess, 1902, III, pages 151–152). Potanin, crossing at the headwaters of the Nomin River (Plate IV) noted "parallel chains of granite and porphyry with an almost meridional trend and particularly steep eastern declivity." Potanin, coming from the north, encountered granite, porphyry, and clay-slate down to about 45° N. (Suess, III, page 153). Prjevalski (1877), traveling northward from Peking to Dolon Nor, reports gneiss and granulite for one hundred and eighty versts on the western slope of the Great Khingan (about Lat. 42° 20′ N., Long. 116° 20′ E.).

> Northwest and west of Dolon Nor the Mongolian platform rises at once to over 2000 meters; on the summit, the previously rocky character of the landscape disappears and we suddenly enter the monotonous Gobi . . . The town of Dolon Nor stands on ancient rocks traversed by quartz veins; then follows to the northwest quartz-porphyry, and the steps which take us to the summit of the Gobi appear to be formed of the same rock. (Suess, 1902, III, page 153.)

Upon the ancient complex rocks lie floods of lava, chiefly basalt, which probably are genetically related to fault movements. Suess mentions "recent volcanic rocks . . . near Nerchinski-Savod, along the upper Argun and on Lake Kulun (1902, III, page 151)." Nerchinski-Savod is on the Argun River, about Lat. 51° 20′ N., Long. 119° 30′ E. Manakin reports an extinct volcano with a well-preserved crater on the east side of the Khingan, at the bend of the Nomin River (1898, pages 1–79). Potanin notes remains of two other craters near the town of Mergen. "Thus the town of Mergen is surrounded by a volcanic region of recent date, which measures two hundred versts from west to east." . . . and "forms an eastward extension of the volcanic rocks of the Khingan and at the same time a part of the border of the eastern Gobi." (Quoted by Suess, 1902, III, page 152.)

Other extensive lava fields lie west of the Khingan. Mushketov (1881) describes a lava field north-northwest of Dolon Nor, in the hills called Bogdo Ola (Lat. 43° 35′ N., Long. 115° 30′ E.), where he saw a volcanic cone that still retained its crater. Very recently Père Emil Licent and Père Teilhard de Chardin visited this general region, and at about Lat. 42° 30′ N., Long. 115° E., discovered large areas of basalt and a chain of volcanic cones. The basalt overlies sediments carrying an Upper Pliocene fauna which would serve to suggest an approximate date of either late Pliocene or Pleistocene for these outpourings. (Teilhard, 1924 *c*, and personal communication, 1924, to W. D. Matthew.)

Suess believed (1902, III, page 120) that the lavas of the Khingan Mountains probably were correlated with the lava fields of southern Mongolia. But later studies have shown that the lavas range in age from probably as old as Oligocene to certainly as young as late Pliocene, so that correlation of the lavas must be left for future careful investigation.

The eastern side of the Khingan descends abruptly to a broad lowland, and is considered to be a fault-scarp by Mushketov. Von Richthofen also took this view, adding: ". . . it seems that the name Khingan applies to the steep eastward-facing scarp of a gentle up-swelling of the margin of the plateau from the west." (1877, page 34.) On page 147 (1877) von Richthofen also says: "the gentle up-arching of the Khingan forms the boundary of the northern and eastern transition region [from the Gobi outward to the drained and watered regions], but is more of a connecting link between them than a separation of them." On page 519 of Volume II, he adds:

> If we omit the tongues of the plain that thrust in long valleys into the mountains, the plain [the great plain of China] is separated from the mountains by a straight line . . . If we prolong this line north-northeast, it coincides with the eastern descent of the mountains of Shansi rimming the Bay of Peking. This line, nearly at right angles to the trend of the Kuen Lun ranges, is of great significance in the configuration of northern China, and it is perhaps not by accident that the Khingan, which is likewise an up-arched plateau margin and only offers the aspect of mountains when seen from the east, lies in the prolongation of this very line.

He considers that the uplift of these northeastward-trending mountains took place at some time later than Lower Jurassic.

Willis, commenting upon von Richthofen's line of dislocation, the Khingan line, says in part (1907, II, page 106):

He does not cite any evidence of faulting on the line itself, it being drawn indeed in the plain of alluvium; and according to our observations on three different sections, the passage from the plain to the mountains is a zone of warping, not a line of dislocation. Where, in latitude 49°, the Siberian railroad descends to the Sungari, the eastern slope of the Khingan is a tilted, dissected, but unbroken peneplane. Where the Sha-ho, in latitude 39°, has cut its autogenous valley, . . . the effects of modern warping are obvious. Normal faulting, though present in the Ning-shan basin, occurred at a remote Tertiary date, and erosion has reversed the relief to which it gave rise. Again, in latitude 31°, where the Yangtze emerges from its profound gorges at Ichang, the mountain slope that faces the far-spreading river plain is a tilted surface of erosion, showing a continuous stratum of Carboniferous limestone, which toward the base is overlaid by the K'uichow red beds in appropriate stratigraphic sequence. It is a warped surface, not a fault; and there is no evidence that it is limited by a fault at the base.

Willis then cites two places at which von Richthofen crossed the Khingan line—one in latitude 33°, the other in latitude 38°. Von Richthofen found a simple flexure at the first, but at the more northerly crossing he found that the descent to the plains was made by a series of step-faults with the downthrow on the east. Willis points out that the moderate faulting in this case "is not inconsistent with the warping observed elsewhere," and concludes that the weight of evidence favors the view that the Khingan line is to be regarded "as a zone of monoclinical flexure, not as a fault" (1905, page 7).

Summary of the eastern boundary

From the foregoing facts, we may conclude that the history of the Khingan range has been essentially as follows: An ancient mountain range composed of folded schists and igneous intrusives was wholly planed away by erosion before the uplift of the present Khingan. The new range is due to simple warping or arching of the peneplaned rocks, which are similar to those of the oldrock floor of the Gobi. The lava fields along the Khingan were formed by volcanic outpourings which accompanied the growth of the present range during Tertiary and Pleistocene time.

THE SOUTHERN BOUNDARY

The southern boundary of the Gobi is complex, and locally difficult to define. In the east it is the edge of a great dissected plateau. The central section in the Ordos is indefinite. Here the Yellow River makes a great loop toward the north, east, and south, encircling the Ordos platform. Whether the Gobi basin should include this block, or whether the boundary should be placed along the hills north of the Yellow River is an open question. On the whole, however, it seems advisable not to separate the two regions, because in the later history of basin making, they have behaved essentially as a unit. West of the Ordos, the boundary is to be placed along the Nan Shan and Richthofen ranges. There are thus three sections of the southern boundary—the eastern section, composed of a plateau edge, largely capped with lava flows; the central section, composed of hills that swing around the southern end of the Ordos; and the western section, composed of great mountain chains.

Southern boundary—eastern section

The southern boundary of the Gobi in the region of Kalgan is formed by the edge of uptilted Tertiary lavas (Figs. 1, page 8, and 5, page 47). The margin of the lavas presents an imposing scarp, descending abruptly into China on the south, and sloping very gently away into Mongolia on the north, so that it forms another "of the great steps by which Central Asia descends to the sea," as Mushketov so aptly said of the Khingan. The scarp at Kalgan does not mark a fault, but is simply an erosion scarp. The only faults we have been able to trace in this region are downthrown toward the north, that is, toward Mongolia (Fig. 5, page 47). The scarp, therefore, indicates a truly impressive retreat, through erosion, of lava sheets that once must have covered a far greater area than at present.

The lavas overlie a thick formation of conglomerate, sand, and sandy clay in which dinosaur bones have been found. There is apparently a slight but significant angular unconformity between the sandstones below and the lavas above. The lavas dip northward at a gentler angle than do the sandstones. Andersson (1923 *a*, page 99) and Barbour (1924,) have reported the presence of plant beds, believed to indicate Lower Oligocene age, between the lava sheets.

According to von Richthofen's map, the lavas continue to the westward for fifty miles to about Lat. 40° N., Long. 114° E. From this point (Plate IV) we must again follow Suess's summary for the general description of the region (1902, III, pages 255–266). Prjevalski observed limestone hills called Khara Khada, or Shara Khada, which appear from underneath the lava cover in about Lat. 41° 30′ N., Long. 113° E., and form a range that strikes southwestward toward the Yellow River. Two other ranges, the In Shan and Muni Ola, continue the general line of the Shara Khada along the northern side of the Yellow River valley. The ranges are not in one line, but overlap one another (Plate IV). A similar chain of ranges lies farther to the north and includes the Suma Khada, Sheiten Ola and Narin Ola ranges. They are all formed of short overlapping ranges, and all are of ancient rocks—dominantly schists, gneisses, and crystalline limestones, cut by large bodies of granite. Suess remarks (1902, III, page 257) that the strike of these old disturbed rocks does not agree with the present strike of the ranges. Probably the ranges follow Tertiary or post-Tertiary fault lines.

Southern boundary—central section

The Khara, Narin, Argilintai, and, farther south, the Ala Shan Mountains bend like a great framework around the corner of the rectangular course of the Yellow River. The eastern side of this frame is made by the fault-block mountains of Shansi. Within the mountain-framed bend of the big river lies the semidesert land of the Ordos. It is a platform of low relief which the Comte de Lesdain says has sunk somewhat and now lies at about 1500–1600 meters, without high mountains or deep valleys (1908). It is bounded rather indefinitely on the south by hills from which flow a number of tributaries to the Yellow River and the Wei Ho.

The Cambrian limestones in the Ordos are still nearly horizontal, indicating that the region is part of a very stable block of the continent,—a plateau land very like the Angara element in central Siberia (Fig. 127, page 295).

Suess points out the strong contrast between this ancient plateau structure and the complexly folded oldrock floor of the Gobi. He adds (1902, III, page 258): "The difference between the Gobi and the Ordos could not be more complete. In the contrast between the ancient folds of the Altaides and their foreland, the Ordos, we find a parallel to the contrast between the folded Alps and their foreland." However, Suess has compared only the folded and the non-folded units of the oldrock floor; the contrast does not extend to the younger sediments that overlie this floor. Since the time when the latest folded mountains of Mongolia were peneplaned, Ordosia has been broken up into a series of elevated and depressed blocks, and the Ordos proper has shared the warping and inland deposition of the Gobi. In the Gobi, the oldest sediments resting upon the peneplaned floor of complex rocks are of Lower Cretaceous age. The peneplaned oldrock floor of the Ordos is similarly covered by inland basin sediments, the oldest of which, according to W. H. Wong, are now believed to be Cretaceous (1924, personal communication). Despite the warping that has caused the great detour of the Yellow River toward the north, around the margin of the Ordos platform, it seems fair to reckon the Ordos as essentially a subprovince of the Gobi.

Southern boundary—western section

The southern boundary of the Ala Shan desert, which lies west of the Ordos, is formed by the Nan Shan ranges. In describing the relations of the Nan Shan to the Gobi basin, Suess (1902, III, page 223) draws his data chiefly from Obruchev's work (1900, page 581). The Nan Shan is a great and complex mountain range, striking a little south of east, and is cut by a series of longitudinal faults. North of it lies a broad lowland bounded by the Lung Shan, often called Pei Shan, which means North Mountains, in contrast to the South Mountains or Nan Shan. The intermontane depression which forms the lowland of Kansu, is watered chiefly by streams from the Nan Shan and Richthofen ranges. Most of these streams cross the depression at right angles to its trend, and pass through gaps in the Lung Shan into the desert beyond; only one runs parallel to the trend, collecting affluents from the mountains, and then passes through a gap in the Lung Shan to become the Edsin Gol in the Gobi. Their courses lie upon basin sediments in the lowlands, and upon the complex rocks of the ancient floor in the mountains. A critical study of the relations of the rivers, the basin sediments, and the old-rock floor, would yield a rich harvest of discovery concerning the structure and age of this part of the Gobi basin.

Obruchev's cross-sections of the Lung Shan (1900, I, page 553) show clearly that the rocks have been folded in one revolution, and later have been faulted by quite another series of earth movements. The folding took place after the Carboniferous period, as Carboniferous strata are involved in the folded structures. Three of the four faults are represented in the section as downthrown on the north side, indicating that the depressed region lay north of the range, where the Gobi lies. Along the north flank of the Lung Shan, later sediments of the inland Gobi basin are tilted up, indicating that part, or all, of the uplifting of the Lung Shan is of later date than the deposition of the sediments. Similarly in the Nan Shan and Richthofen ranges, the basin sediments have been displaced, according to Obruchev; therefore, in part at least, the uplift must be younger than the basin sediments.

Briefly summarizing these facts and the inferences they support, the Nan Shan and Lung Shan owe their present height to warping and faulting, not at all to folding. Here, as elsewhere throughout the Gobi region, the ancient folded mountains were eroded away before the basin sediments were deposited. The modern uplift is later than some at least of the basin sediments.

THE WESTERN BOUNDARY

On the west, the boundary is still more difficult to define, because we pass farther into the vast undrained interior of Asia, and must choose a boundary between basin and basin, not between inland basin and continental slopes that drain to the sea. Two such enclosed lowlands open from the Gobi,—the Tarim or Lop Nor on the southwest, and Dzungaria on the west.

Between the Gobi and each of these great basins there is a lowland gateway which probably is a peneplaned and warped divide, not unlike the broad low saddles that separate the minor basins within the Gobi. Between the

Dzungarian gateway and that of Lop Nor, the Tien Shan mountain system thrusts far eastward, dying out at about the 100th meridian. The two gateways can hardly be considered as boundaries of the Gobi. They are, indeed, merely the connecting links between subdivisions of one great physiographic unit. It seems logical to include the mountain-circled basins of Dzungaria and Lop Nor and the Gobi in one central Asiatic basin province.

The Tien Shan is one of the largest mountain systems of Asia, with a total length of about thirteen hundred miles, and a maximum breadth of nearly two hundred miles. The range Bogdo Ola, east of Urumchi between latitude 88° and 92°, is geologically the best known part of the Tien Shan. Here Merzbacher (1916), Groeber (1914), Machatschek (1918), Friederichsen (1899, 1904, and 1919), and others have conducted careful studies. We briefly summarize the work of these authorities. The Bogdo Ola rises from the southern border of the Dzungarian lowland to an altitude of nearly twenty thousand feet, above which three splendid peaks rise to 21,330, 21,370, and 20,690 feet. From the lowest peak the western part of the chain drops abruptly in sheer cliffs nearly ten thousand feet, to a depression that separates the lower western part of the chain from the high central part (Friederichsen, 1919). On the south the range sinks abruptly to a long desert depression, lying about 4,200 feet above sea level. Beyond this lowland is a minor range called the Djargos, the southern front of which drops sheer into the Turfan lowland, whose floor is 720 feet below sea level. On the north, the first and lowest part of the range consists of Jurassic conglomerates, sandstones, shales, and marls, cut by younger igneous intrusive rocks: this series is eroded to a peneplane, and downthrown along a fault (Friederichsen, 1919). South of the Jurassic belt is a series of more or less strongly metamorphosed slates, quartzites, graywackes, breccias, hornfels, and altered eruptive rocks. Groeber (1909, 1914) considers these to range from Lower Carboniferous to Permian, but fossils are lacking. The high central range includes older rocks that rise in a monstrous scarp, three thousand meters above the northern parts of the range, harboring splendid hanging glaciers. The disturbed Jurassic beds and the folded and metamorphosed series which Groeber has called Palæozoic are dislocated along fault lines which cut and displace the folded structures. Therefore the folding must have been wholly completed before the growth of the present faulted mountains began. Such a history is very similar to that of the eastern Altai as determined by the Third Asiatic Expedition. It also agrees with the masterly summing up of this range by Obruchev, who concludes (1915, page 321):

> But all later observations on the Tien Shan system, as well as the Russian Altai, compel us to doubt seriously the conclusions of Suess as to the simultaneity of the

folding and faulting movements in central Asia . . . Large mountain-making movements, creating entire ranges of bow-shaped folds with their convexity turned toward the south, and extending from the Russian Altai to the Tien Shan, were completed at the very close of the Palæozoic or at the beginning of the Mesozoic. Then disjunctive movements began creating numerous faults . . . which appeared with special vigor at the end of the Mesozoic or in the beginning of the Tertiary period. The lines of rupture . . . diverged . . . from the direction of the Palæozoic folds much oftener than they coincided with that direction. By these two diagnostic evidences—diversity of the time of occurrence and lack of agreement in strike—the movements of folding and of disjunctive dislocation prove to be separated one from another; and it seems hardly possible, as Suess proposes, to reckon the dislocations as a supplement to the plication-movements.

This analysis constitutes a definite advance from the view propounded by Suess, in that Obruchev has recognized a period of mountain making characterized by fault movements, as distinct from the more ancient revolution which was characterized by folding of the rocks.

The correctness of Obruchev's general conclusions, as far as he may have intended them to apply to the Gobi region, is thus confirmed by our more recent studies, and the fact that our analysis of the region has brought out many additional details rather enhances than diminishes the value of his pioneer work. Our own results agree very well with this sequence of events. We go farther, however, in recognizing the virtual peneplanation of the folded Jurassic series, and the development of the Han Hai in entirely new depressions, formed by the warping of the post-Jurassic peneplane. We also recognize (1924, *b*) that the Han Hai deposits began earlier than Neogene, in Lower Cretaceous time, that they are of diverse origin, and that they are not by any means the simple filling of large lakes. We believe that warping and faulting took place intermittently through the time occupied by the deposition of the basin sediments, and that the relief formed by faulting was more than once peneplaned. Although movements went on intermittently throughout the Cretaceous period and the Cenozoic era, the chief mountain-making periods were probably the Pliocene and the Pleistocene.

The following facts and inferences have been developed in this discussion of the Gobi borders:

1. Warped borders form the lip of the great basin on the Khangai, Kentai, and Khingan fronts.

2. The border on the Kerulen River front is probably a compound fault-and-warp.

3. On the Tannu Ola and Nan Shan fronts, the wall of the basin is a fault-scarp.

4. Along the Ala Shan, Yellow River, and In Shan front the borders are

faulted, if we agree with Suess in classing the Ordos as a region quite apart from the Gobi, but if we include the Ordos as part of the Gobi, the boundary is the warped southern margin of the Ordos.

5. The basins of Dzungaria and Lop Nor, lying west and southwest of the Gobi, are virtually continuous with it and are connected with it by low warped gateways.

6. The structure lines of the Gobi are quite in accord with those of the surrounding mountains. The oldrock floor of the Gobi is composed of rocks essentially the same as those of the surrounding lands. In the ancient disturbed rocks and in their structure lines, there is, therefore, as Suess has justly remarked, no boundary between the Gobi and the surrounding regions. Nevertheless there is traceable a tectonic boundary, formed of later warps and faults, which marks out the Gobi as an inland basin; and the movements that have determined this basin character are not older than post-Jurassic. They seem on the whole to have culminated in the late Tertiary and Pleistocene.

PART II

ROUTE STUDIES OR ITINERARY

PART II—ROUTE STUDIES OR ITINERARY

INTRODUCTION

THE TASK OF A GEOLOGICAL RECONNAISSANCE EXPEDITION

It is of prime importance for a geological expedition to keep in close interpretative touch with the strata or other rock formations along the route of travel, for the resulting information forms the basis of such additional exploratory investigations as the country seems to warrant. This further study may resolve itself into acquiring collections of fossils for palæontologic purposes, or into a search for important fossil fields, with a view to their future exploitation. It may strive to determine the ages of the strata and to read something of their geologic history, to locate valuable mineral deposits, to solve the detail of local geologic structure, or to interpret more clearly the meaning of the surface features of the country.

Important finds in any field, of course, may be made by accident, but no scientist expects to reach his larger discoveries other than by careful and systematic work. In any case, he tries to weld his observations into some form of reconnaissance interpretation. A mineral deposit, a fossil field, or a surface feature has a good reason for being where it is, and it acquires added significance because of its surroundings and history. It may not be a geologic achievement to discover such a feature, but it is a geologic problem to explain it, and to use such factors from the record as may lead to other discoveries. Without such interpretation most finds have little more significance than the isolated specimens of a museum, whereas, when properly connected, they not only constitute a definite chapter in local geologic history, but may lead to still more important finds which would otherwise escape observation.

Fossil bones had previously been found in central Asia, but they meant little or nothing to the people who found them—perhaps they were "dragon bones," good for medicine or magic! An occasional fragment was carried away from the desert and reached hands of greater competence, but without corresponding field observations and opportunity to connect with the geologic story, they have added little to an understanding of this great continental area.

Such considerations explain in a measure why the Third Asiatic Expedition has been successful. To the chances of accidental discovery common to all expeditions was added the result of scientifically directed search based on a step-by-step field interpretation of the geology; to the large collections of fossil material were added the determination of the structural setting and of stratigraphic relations, and the evidence of origin and subsequent changes belonging to the same deposits. Thus the strata of the desert basins have been subdivided into formations having a reasonably definite age and history. Their relations, one to another, have been traced structurally as well as by their fossil content. The detail of the geologic column has been extended beyond anything that had previously been attempted in central Asia, the history has taken on a more definite form, and now the region can be compared more satisfactorily with other regions of the earth.

This is not the first time, of course, that the sedimentary formations of the Desert of Gobi have been described. Von Richthofen, in the winter of 1871–1872, entered the southern part of the basin, where, it appears from his description (1882), similar geologic conditions prevail. He called the sediments the "Han Hai beds" (1877, I, page 25). Obruchev (1900, I, page 69) covered a portion of the same route in 1892 and gave the name "Gobi Series" to all these superficial sedimentary deposits. Neither scientist subdivided the series or determined their age with any considerable accuracy. Neither seems to have suspected their complexity of make-up, and neither unraveled the structural or the palæontologic story. One of the accomplishments of the Third Asiatic Expedition was to subdivide, identify, and correlate the members that make up the desert basin sediments, to discover their structural relations, and to collect their fossil content. We now know that they form a complex of several distinct groups of strata, representing an immensely long period of geologic time, from the Lower Cretaceous to the present. Nearly every period is represented in the Gobi, and no fewer than fifteen separate identifiable formations of historical and palæontological significance have been added to the geologic column. The identification of these members, showing that definite periods of Mesozoic and Tertiary age are represented and that they contain fossils both characteristic and rare, is the most fundamental stratigraphic contribution of the Expedition.

In this way the Gobi series of Obruchev has been subdivided and has taken on a more definite meaning, expanding its history to include a much greater range of the geologic column than previous investigators had assigned to it. The limits of some of the formations have been drawn, general terms have been replaced by others of more specific time value, and the several members have been given a very different significance in the geologic history of the region. For example, we find that three sedimentary formations—the Ondai

Sair, the Hsanda Gol, and the Hung Kureh—which are found in the district immediately north of the Baga Bogdo range of the Altai Mountains, and which together represent the Gobi series, are of widely different age from one another. In the first, there are dinosaurs of Lower Cretaceous type; in the second, mammals of mid-Tertiary type; and in the last, mammals of a time just preceding the Ice Age. At Iren Dabasu, at Djadokhta, at Oshih, as well as at many other localities, still different groupings occur, dependent on the shifting conditions of deposition and denudation that accompanied the successive warpings of the Gobi floor.

At most places the "Gobi Series" is not a series at all, but remnants of several different series separated by significant breaks in the record. Some of these gaps correspond to deposits which are still to be found in adjacent territory. The whole list of distinguishable constituent members together makes a formidable array, covering a long series of events and a long succession of life forms, and adds a big chapter to the story of central Mongolia.

Whether such a reconnaissance deserves to be regarded as sufficiently complete to warrant publication, is a fair question. It is at best a hurried, preliminary study with the object of determining major features as a guide for later, more detailed work of many kinds. Its value, of course, may be measured by its adequacy in meeting the demands for which it was organized. A geological reconnaissance which has solved the formational structure, outlined the major historical events, established their sequence, and assembled the criteria in such a way that they can be used successfully, has perhaps a right to be considered a unit of investigation. If, in addition, these criteria have already been used to advantage in the progress of the field work in a region which bids fair to become a famous source of scientific returns, there may be good reason to put these reconnaissance results into permanent form for unrestricted use.

RECORDING OBSERVATIONS

It is not easy to record in usable form the thousands of observations made in so extended a traverse as that of the Third Asiatic Expedition in its reconnaissance of 1922 and 1923 in central Mongolia. Unless they are organized they become too unwieldy to be of much value beyond that already served in the progress of the reconnaissance itself. Probably the simplest method is to avoid printing the record, and to give instead only the conclusions and interpretations reached. It is evident, however, that this alternative is open to serious objection, particularly because the work has had to be done too rapidly for uniformly reliable results. It is only fair, therefore, that the major facts of observation should be given without involving them in much interpretation beyond the simplest inferences, wherein there is little likelihood of error. It is our wish to make these observations serviceable to others, even though they may lead to a different interpretation, and to this end we have chosen to record the great bulk of elementary data in an itinerary account.

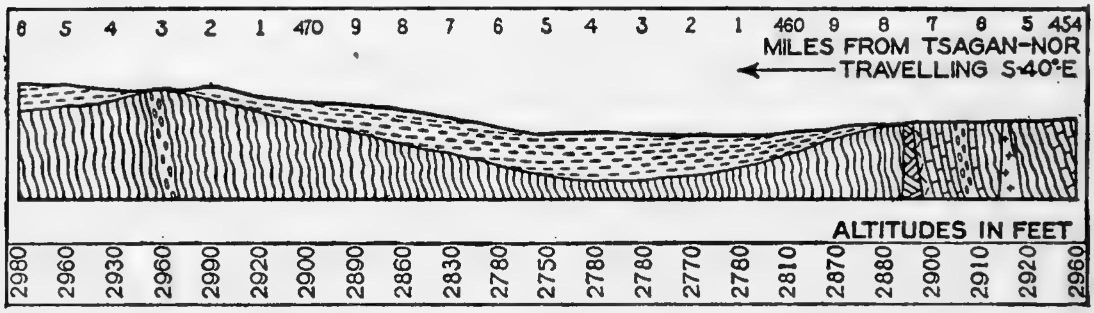


FIGURE 3.—Profile and section illustrating methods of recording observations. The figures below the cross section are the altitudes in feet, as determined by barometer readings. The figures above are miles, representing the distance traveled from Kalgan. The profile of the section is constructed to scale, both horizontally and vertically. The bedding of all stratified rocks is drawn in approximately correct position, recording folding, tilting or horizontal structure. The igneous rocks are indicated by symbols suggesting crystalline structure. The conventional rock symbols are set forth in Plates VI and VII. In the succeeding sections, beginning with Figure 5, only a few of the altitude readings are entered, though all were used in constructing the profile; and the mileages are represented by a graphic scale.

We believe that this account will be more interesting and more readily used if it is in part narrative and descriptive, and in part graphic, represented by profiles and cross-sections running parallel with the text (Fig. 3, and Figs. 5–97). We are well aware that this is an unusual method—one which, as far as we know, has never been followed by a reconnaissance expedition. We are mindful also that to some degree the record thus takes on certain elements of interpretation, in spite of the wish to avoid it; but only such interpretation has been used as that attached to field structure, which is represented in this volume by geologic cross-sections. If presented, therefore, with the explanation that much of the work has been done under rapid movement, requiring hurried observations, and that this graphic method was found in the field to be the most practicable way of recording the mass of data gathered, it will probably serve a useful purpose, and should not lead to any misconception of its value as compared with those special studies where more careful work could be done. It is possible by this means to follow the route mile by mile, and to find the profile, the geologic structure, and the specific rock formation at any point along the trail without difficulty (Fig. 5, *et seq.*). Thus the route section becomes a base from which additional investigations can be projected.

Wherever we were fortunate enough to make many observations, we are confident that the suggested determinations and structures are correct. Wherever the observations are particularly scattered or scanty, and where there is obviously greater doubt about the structural interpretation, we have attempted to indicate that difference of reliability in the accompanying description. Yet rather than leave such stretches blank, we have suggested the underground structure which the evidence best supports, believing that even this is a step toward a better understanding of this very little known region. Wherever the field notes are sufficiently complete, we have used them to construct not only the profile and cross-section of the traverse, but a route map on which it is possible to indicate more or less of the immediate side country and guide points.

The scales of the itinerary diagrams are uniform, each covering thirty miles, although special cross-sections are constructed on a larger scale. In

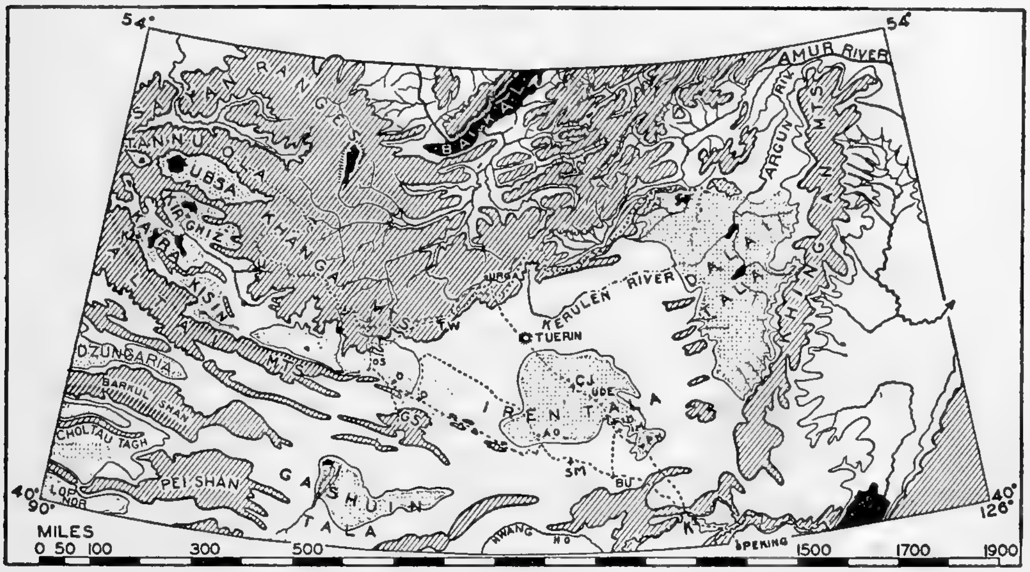


FIGURE 4.—General location and route map. Mountainous areas are shaded in slanting lines. Lowlands are white, and the deeper depressions are stippled. Lakes are colored black. The routes of the Expedition in 1922 and 1923 are drawn in broken lines. Index letters along the routes indicate the following places: K (northwest of Peking) Kalgan; P K, P'ang Kiang; I M, Irdin Manha; I D, Iren Dabasu; C J, Camp Jurassic; T W, Tsetsenwan; O S, Ondai Sair; O, Oshih; G S, Gurbun Saikhan; D, Djadokhta; A O, Ardyn Obo; S M, Shara Murun; B U, Boltai Urtu; U (south of the K of Khangai), Uliassutai; K (north of the A of Altai), Kobdo. The Ubsa, Kirghiz and Kara basins constitute Pievtsov's "Valley of the Lakes."

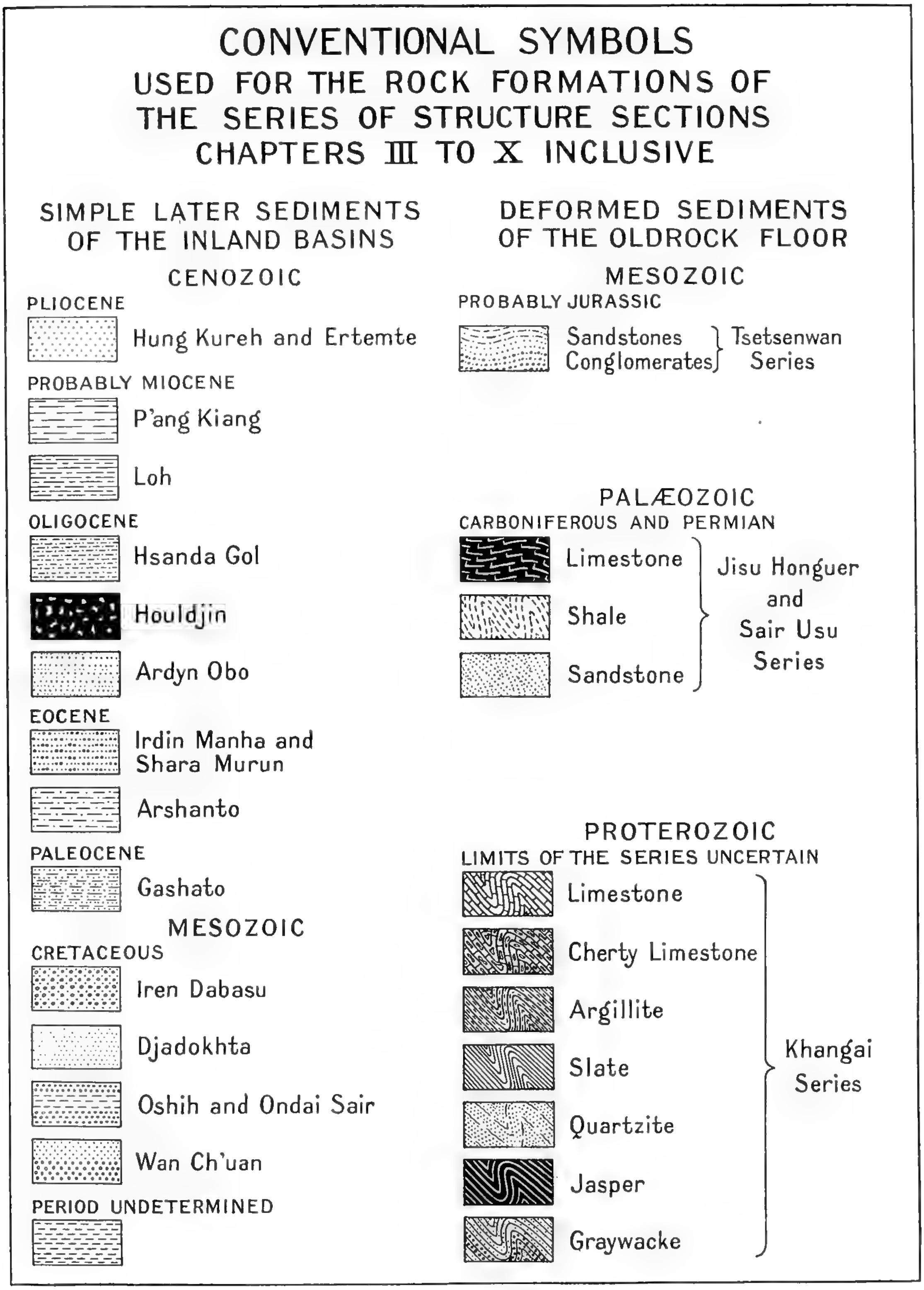
order to avoid possible confusion from this cause, we have taken pains to carry a scale of miles on every sheet, indicating not only the scale of the drawing but also the distance from the starting point of the traverse.

The running descriptive account which accompanies the continuous profile and cross-section covers the major points of interest in the corresponding portion of the itinerary (Fig. 4 and Plate IV). Of course, the text and its corresponding illustration do not in all cases, fall on opposite or on following pages but the description always follows the same order as the cross-section and forms a continuous story of observations. In large part, these observations constitute the basis of such conclusions as the Expedition has been able to formulate concerning the geology of Mongolia.

But the data are not wholly confined to the route traverses. Where an area was found which combined unusual opportunities for all the scientists of the Expedition, time for longer study was given, and more detailed observations were made. These studies form the basis of contributions included in Part III of this Report. Some of the special and local studies covered particularly critical spots, and some of them have been examined in as great detail as is ordinarily done in countries much more highly favored with geological service. Details of stratigraphy, structure, and process were worked out in certain areas, which led to extensive correction of the geologic conclusions based on the reconnaissance traverses alone.

The itinerary observations, together with the special and local studies, have been reorganized, therefore, in the later discussion of the larger geologic problems. The assembled material, representing the summaries and tentative conclusions of the geological section of the Expedition, constitute Part IV of this Report.

PLATE VI.


CONVENTIONAL SYMBOLS
USED FOR THE ROCK FORMATIONS OF THE SERIES OF STRUCTURE SECTIONS CHAPTERS III TO X INCLUSIVE
SIMPLE LATER SEDIMENTS OF THE INLAND BASINS
CENOZOIC
PLIOCENE
Hung Kureh and Ertemte
PROBABLY MIOCENE
P'ang Kiang
Loh
OLIGOCENE
Hsanda Gol
Houldjin
Ardyn Obo
EOCENE
Irdin Manha and Shara Murun
Arshanto
PALEOCENE
Gashato
MESOZOIC
CRETACEOUS
Iren Dabasu
Djadokhta
Oshih and Ondai Sair
Wan Ch'uan
PERIOD UNDETERMINED
DEFORMED SEDIMENTS OF THE OLDROCK FLOOR
MESOZOIC
PROBABLY JURASSIC
Sandstones
Conglomerates
Tsetsenwan Series
PALÆOZOIC
CARBONIFEROUS AND PERMIAN
Limestone
Shale
Sandstone
Jisu Honguer and Sair Usu Series
PROTEROZOIC
LIMITS OF THE SERIES UNCERTAIN
Limestone
Cherty Limestone
Argillite
Slate
Quartzite
Jasper
Graywacke
Khangai Series

CONVENTIONAL SYMBOLS
USED FOR THE ROCK FORMATIONS OF THE SERIES OF STRUCTURE SECTIONS CHAPTERS III TO X INCLUSIVE
(CONTINUED)

EARLY PROTEROZOIC
THE WU T'AI SYSTEM

- Dolomites
- Crystalline Limestones
- Quartzites
- Phyllites
- Schists

ARCHÆOZOIC
THE T'AI SHAN COMPLEX

- Crystalline Limestones
- Injected Schists
- Gneisses

IGNEOUS ROCKS
VOLCANIC FLOWS
ASSOCIATED WITH THE LATER SEDIMENTS

- Rhyolites
- Trachytes
- Andesites
- Basalts

IGNEOUS ROCKS
INTRUSIVE PORPHYRIES
BELONGING TO THE OLDROCK FLOOR

- Rhyolite Porphyries
- Granite Porphyries
- Trachyte Porphyries
- Andesite Porphyries
- Basalt Porphyries

MASSIVE IGNEOUS ROCKS
CHIEFLY BELONGING TO THE MONGOLIAN BATHYLITH

- Granites
- Syenites
- Diorites
- Gabbros

BASIC IGNEOUS ROCKS
PROFOUNDLY ALTERED

- Serpentine

CHAPTER III

FROM KALGAN TO IREN DABASU

THE ground on which Kalgan stands is alluvium, or flood-plain deposit, of the river Yang Ho, which periodically overflows its banks and spreads destruction along its course; but the rugged hills above Kalgan, at the entrance to the Wan Ch'uan Hsien Pass, are made up chiefly of igneous rocks (Figs. 1 and 5).

KALGAN TO WAN CH'UAN PASS

For the first few miles the traverse was made over a low spur on the side of the valley, where the roadway is cut down fifteen or twenty feet into volcanic tuffs (Specimen 6, A.M. 9695) and associated lavas (Specimen 7, A.M. 9696), which together form the foundation rock. A small tributary gulch just above this spur is partially filled with loess, which exhibits the characteristic habit of this material. Nowhere else on the whole summer's traverse was typical loess again encountered. Apparently it is entirely a border accumulation and not at all characteristic of the interior desert region.

The lower pass

The igneous formations belonging to the lower half of the Wan Ch'uan Hsien Pass are in peculiarly fresh condition except on the lower portions of the valley sides, where long exposure to weathering has led to the usual decay, and it is here only that the rocks of this formation show enough weakness to yield noticeably to the wear of travel. In the course of centuries the wear of wheels and the tramp of caravans have cut veritable miniature canyons into the rock. The types of rock include rhyolites, trachytes, trachy-andesites, porphyritic felsites with corresponding porphyries, and a great variety of tuffs. Structurally they present great confusion, and leave one in uncertainty as to their intimate relation. Some of them are clearly lava flows and surface tuff accumulations in which there is a crude structure that gives locally some clue to original conditions, but for the most part the structure is obscure.

It is evident that intrusions break through the simpler surface flows, not only cutting off the original continuations, but otherwise disturbing the earlier members.

The variety of rock observed is much greater than this list of types would suggest. A very great range is represented, the like of which had not been seen elsewhere in our traverse, and was not to be encountered again for several hundred miles. The whole complex, however, has a definite character, due to the prevalence of felsitic and fine-grained porphyritic types of rock, to the obscurity of their structural relations, and to their habit of breaking into small angular bits, so that it has been possible to identify the same formational conditions at many other places in the course of our work in central Mongolia. The igneous eruptive complex continues halfway through the pass —indeed, through the whole of the narrow portion of about five miles. Beyond it the valley opens out considerably, and although traveling is difficult, the gorge form disappears.

We found no clue to the age of the igneous rocks exposed in the lower portion of the Pass, except the fact that they are not metamorphosed and not intimately deformed, although much broken. The deformational habit, coupled with the peculiarities of rock type and structure, belongs, as we afterwards learned, to great igneous eruptive complexes associated with strata which we judged to be of Jurassic age. At other places, similar porphyries underlie the Lower Cretaceous sediments, a fact which tends to support the inference of the Jurassic age of the porphyries.

A very rugged topography is carved on this complex and forms a frowning, jagged barrier rising to one thousand feet and more in the immediate hills about the city (Fig. 5). It is surmounted by a deeply dissected escarpment, rising two thousand feet higher to the top of the Pass and extending to the edge of the Mongolian plateau.

Wan Ch'uan basin and the upper pass

Where the road emerges from the narrow gorge into the open portion constituting the upper half of the Pass, the igneous complex is terminated abruptly against a fault. Higher ground lies beyond, but its slopes are smoother, because the underlying rocks are of a simpler and less resistant type. They are sediments that lie nearly flat, dipping only slightly northward toward the interior of the continent. Curiously enough, they are dragged abruptly upward at the fault margin, indicating that the ground upon which we have just entered, despite its greater present surface elevation, belongs in reality to a down-dropped block rather than to an uplifted one. Above the dissected edge of the escarpment lies the Mongolian plateau.

Stream erosion has carved the usual complexity of a dissected surface, but

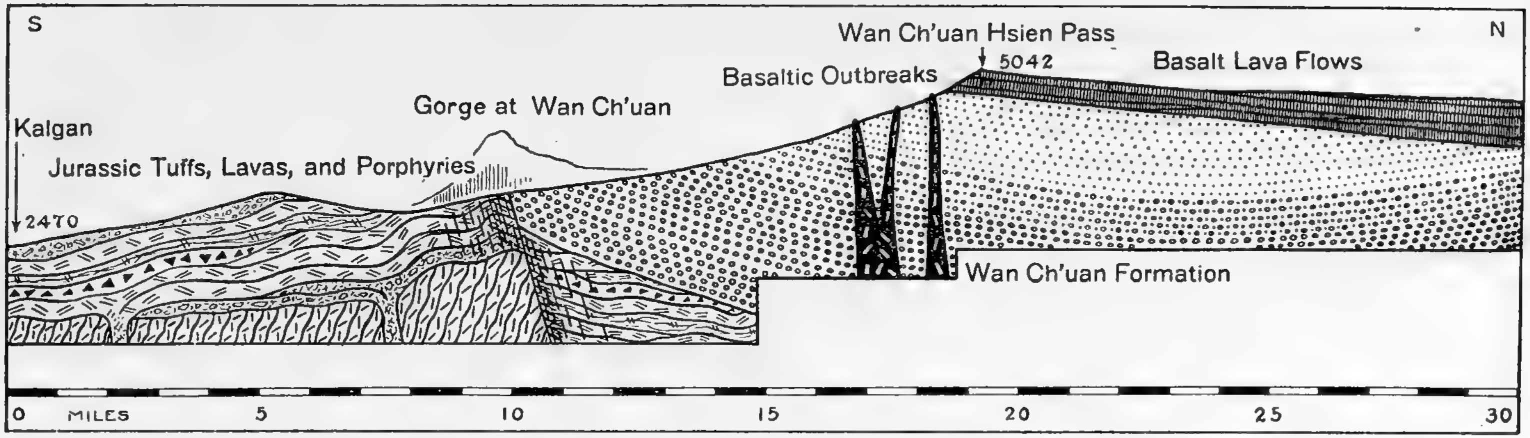


FIGURE 5.—Geologic section from Kalgan to the Wan Ch'uan Hsien Pass. The ancient gneisses, shown as the basement rock, come to the surface east of this section, about opposite mile 9. The younger conglomerates and sandstones north of the gorge contain reptile bones and probably are Cretaceous. The basalt flows are judged by Andersson to be Oligocene. The Wan Ch'uan Hsien Pass lies on the Pacific divide at the beginning of the inland basin of Mongolia.

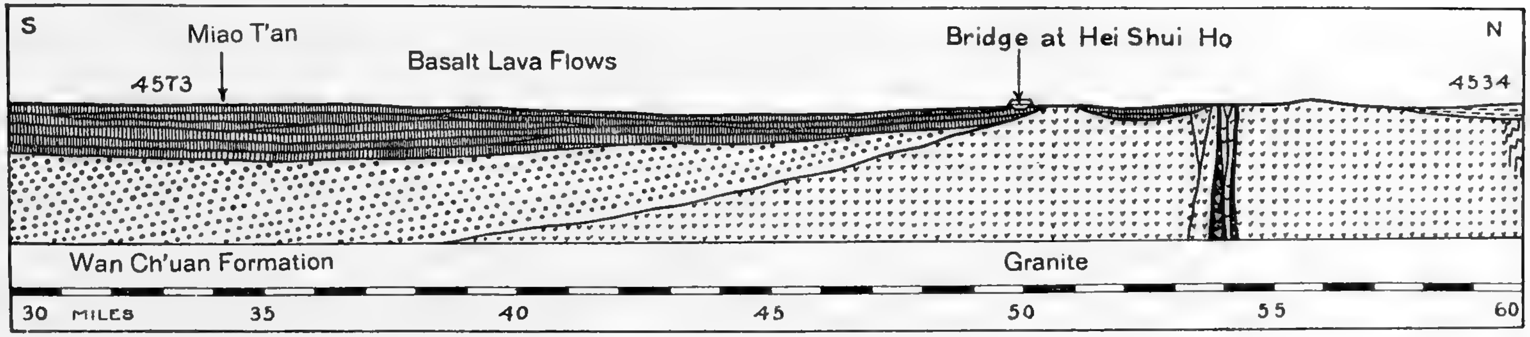


FIGURE 6.—Transition from the Tertiary basalts and Cretaceous conglomerates of the pass to the oldrock floor and shallow sediment basins of the interior.

for two or three miles beyond the fault the topography is comparatively smooth, and the trail rises gently. Beyond this, the climb is more difficult, and the last three miles are as steep as can be traversed successfully with motor equipment such as that of the Third Asiatic Expedition. Thus one mounts, over the edges of a great series of strata, to the top of the Pass.

Two features of this second portion of the Wan Ch'uan Hsien Pass deserve special note:

(a) The double erosion form noted on the dissected escarpment, and

(b) The occurrence of volcanic outbreaks and intrusions.

Midway in the Pass, the sediments bear traces of an ancient, smoothly rounded topography, which was developed by long continued erosion during a preceding epoch (Plate XLI, page 389). In the present epoch these slopes have been sharply trenched by new, steep-sided, precipitous gullies, which give a peculiar double form to the hillsides. Whatever the cause, there has been a rejuvenation, and local erosion is proceeding far more rapidly at the present time than in the preceding cycle. This is probably due to changed climatic conditions—apparently to greater aridity. When rainfall is heavy, a thick mat of vegetation protects the soil so that rainwash tends to produce a gently rolling surface. At the present time the slopes are poorly protected by vegetation, and the attack of running water meets with little resistance. This explanation appears to be more satisfactory than that of change of local base-level, or greater rainfall, or even that commonest of explanations, deforestation by men. Climatic change as an explanation is consistent with many evidences seen in other regions on this extended traverse. (See Chapter XXI.)

At many points in the upper half of the sedimentary series in this stretch of ground there are butte-like hills and unexpectedly rugged spots, which, on inspection, prove to be due to igneous outbreaks. Some of them are necks and plugs and irregular, projecting intrusions; others are dikes and sills; still others are local induration effects produced by escaping gases. All together they represent igneous activity on a considerable scale. At no place is there a very extensive modification of the surrounding strata by the invading material, but locally the structure is disturbed. The most marked feature is an abrupt change of rock type, introducing a great difference in erosion effect. The outbreaks are mainly basalts; some are vesicular, and doubtless volcanic ashes and tuffs were also furnished, which were distributed with the sediments. A thick series of basalt flows forms a cap which constitutes the surface formation inland for many miles.

Here, at the very top, stands the ancient wall that divides China and Mongolia. Here, also, we could see that we had attained, not the top of a mountain range, but the outer edge of a great plateau, a portion of which has been carried away by erosion, while the ground remaining constitutes the

PLATE VIII.

A. VIEW FROM THE HEAD OF THE WAN CHU'AN PASS.

Valley carved in the peneplaned basalts on the inland basin side of the Pacific divide beyond the Wan Ch'uan pass.

B. CULTIVATED FIELDS OF CHINESE FARMERS.

Grain fields of the Chinese settlers developing the agricultural possibilities of the grassland belt of southern Mongolia.

PLATE IX.

A. THE UPLAND AS SEEN FROM THE SECOND CAMP.

Upland of the oldrock hills preserving remnants of the dissected Mongolian peneplane in the Chakhar district of southern Mongolia.

B. CAMP IN THE GRANITE HILLS OF CHAKHAR.

The photograph, Plate IX A, was taken from the top of this hill.

rugged topography and steep ascent of the Wan Ch'uan Hsien Pass from the valleys below—a distance of twenty miles. In that distance the Expedition had climbed nearly three thousand feet and had traversed the splendidly exposed representatives of two great geologic formations,—in the first ten miles the igneous porphyry complex, and in the last ten miles a great thickness of sedimentary strata, having the appearance characteristic of formations belonging to the later periods of geologic time.

The sediments of the younger formation have not been much disturbed or reorganized since the strata were laid down, and present all the evidences of rapid accumulation by water currents. Sediments of this kind are now usually considered to be of continental origin. They consist of conglomerates, sands, and clayey sands—varicolored and rapidly changing in quality and color both vertically and laterally. Bedding is prominent, but differences of resistance to erosion in successive beds are not great enough to have much effect on the topography.

This was our introduction to the simple sediments of the interior country. Such strata ought to carry fossils. Strata of like appearance, found in the interior, yielded abundant returns. On the outward journey little attention could be given to this stretch of ground and a hurried inspection at two or three points yielded nothing. On the homeward trip, however, fragments of reptile bones were found close beside the trail. In structure and dynamic history the Wan Ch'uan formation resembles some of the Cretaceous and early Tertiary formations seen elsewhere in Mongolia, and the fossil evidence favors this view, although an exact determination has not yet been made.

THE PACIFIC DIVIDE TO P'ANG KIANG

The edge of the plateau reached by the Wan Ch'uan Hsien Pass, twenty miles above Kalgan, is a true continental divide. From that point toward the interior the average elevation gradually decreases, and one enters the great basin occupied by the Desert of Gobi (Plate VIII, A). While the elevation at the divide is more than five thousand feet above the sea, at the center of the basin, three hundred miles away, it is less than three thousand feet. From the top of the Pass the streams turn inland, and for nearly six hundred miles the drainage is toward the interior.

For the most part the country is either smoothly rolling or nearly flat (Plate VIII, B). The surface features are all erosion forms governed by the underground rock structure. We soon learned that the topography is related to the deformational history of the region, its faultings and warpings, its igneous outbreaks, and its sedimentary accumulations. The origin of the land forms is genetically connected with the physiographic history that goes back to the time when this region first became an inland basin. Traces of a comparatively ancient erosion are preserved on some masses of the hard rock, whereas features which were developed at a much later time appear on sediments resting upon the oldrock floor. The topography therefore ties up not only with the underground structure but with the dynamic history, and as the relations of these forms come to be better understood, they furnish the first, and in some respects the best, aid in unraveling the geological relations in rapid reconnaissance.

For the first twenty miles after crossing the divide, the rolling basalt hills continue, with enough exposures to determine the character of the formations below (Fig. 6). Weathering and decay have formed a soil that has obscured most of the rock floor, and these processes, together with the stream wash, have produced an alluvium that covers almost the entire surface. The surface material is thus, in part, residuary from decay, and, in part, a deposit from the wash. In many places, therefore, and occasionally over long stretches, it is impossible to determine the exact quality of the underlying rock floor, but its general structural habit is, as a rule, indicated by the topographic features just described. Relying on this evidence, we judge that the basin of sediments, across whose edge the Expedition climbed at Wan Ch'uan Hsien Pass, extends inland many miles, capped by basalt, and, in places, also by sediments covering the basalts. Some of the sediments are doubtless much younger than those of the Pass, and vary greatly in quality from place to place. Granite and other crystalline rocks appear abruptly on the inner margin of the basin. They are doubtless a part of the still more ancient floor on which all the so-called later sediments rest, and they have been brought to the present surface either by faulting or by warping.

From this point onward there is a succession of complex features belonging chiefly to the ancient floor (Figs. 6 and 7). The first large basin in which sedimentation occurred was crossed at or near the 50th mile. A much smaller basin, only a few miles beyond, has one of its limits at mile 75, and then a series of schists, quartzites and slates, cut by diorite, porphyry and granite masses, forms the floor for fifty miles (Figs. 7 and 8). The minor structural relations of these different formational units are not determinable with so little field observation, but the major ones are plain. The schists, quartzites, and slates are comparatively ancient rocks which have been invaded by the granite, and the diorite porphyries have cut both the granite and the schists. It is possible that the oldrock hills are the remnants of an ancient fault-block mountain.

This was our first encounter with a type of granite that we were to see subsequently in a thousand other places, exhibiting a great variety of facies, but always with similar relations to the major formations of the region. Perhaps it is the same also as that seen in Nan K'ou Pass, forming the core of the

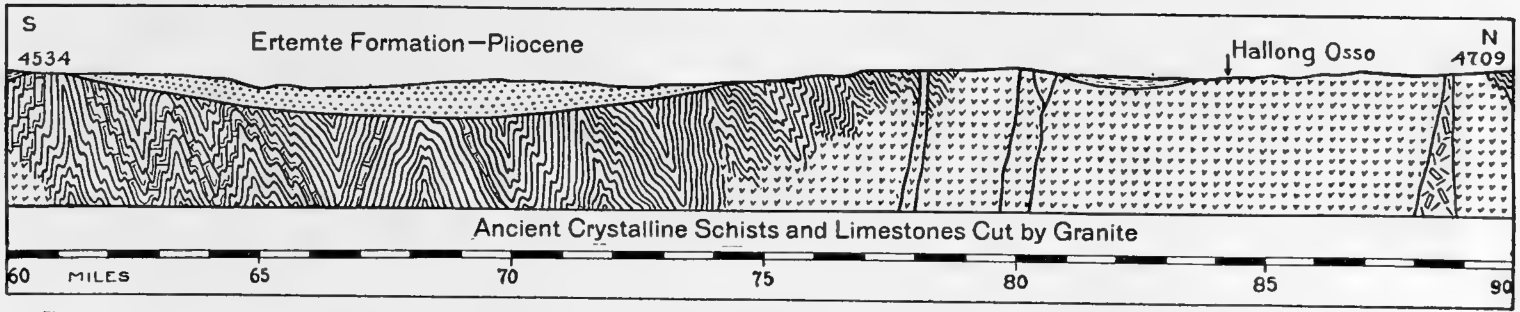


FIGURE 7.—Entry into the rolling hills of Chakhar. The profile, taken along the road, is much smoother than the hilly country. (Compare with Plate IX.) Several shallow sediment-fills, or basins, rest upon the complex oldrock floor. The type locality of Ertemte lies to the northeast of the road, and the sediments here labeled Ertemte are an extension of the basin.

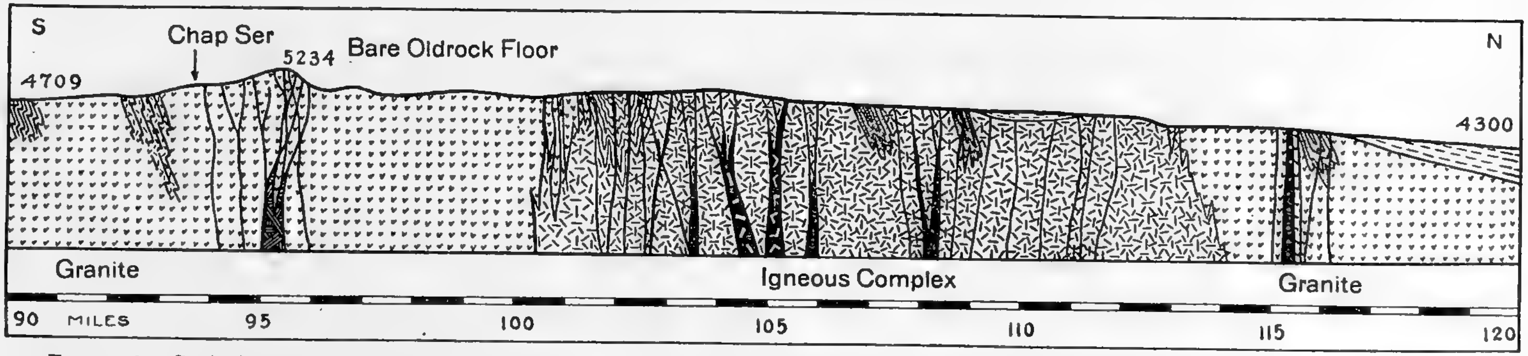


FIGURE 8.—Geologic section through the Chakhar hills. The chief rock is granite, bearing roof-pendants and xenoliths of schist and phyllite. The granite is cut by a great mass of diorite and many dikes.

mountain barrier above the plains of China. It is this granite that we came afterward to recognize structurally as part of a great bathylith underlying the whole Mongolian region, in places penetrating the various oldrock formations of the roof, forming the surface for long stretches, or appearing as intrusions of more limited extent and of more variable quality.

At mile 116 a third small basin was reached, where, because of the cover, the nature of the rock is more obscure; but it is certain, judging from the topography, that the underlying beds should be classed with the basin sediments. Several miles of granite and graywacke separate this tract from a larger basin, which begins at about mile 137, and, except for a low inlier of schists and graywacke, continues for nearly fifty miles, with simple, nearly flat-lying sediments, capped by, or interbedded with, basalts (Fig. 9).

The granite hills of Chakhar

In the granite hills the first glimpse was obtained of one of the great peneplanes of Mongolia. The camp here, Camp Granite Hills, lay one hundred and thirty miles from Kalgan and was reached on the second day (Plate IX, B). It was pitched in a country of rolling hills and broad, open valleys, but from the summit of any of the surrounding hills we looked over a veritable sea of hilltops in every direction (Plate IX, A). From this eminence the irregularities of relief seemed to fail completely in the distance, as they might if the relief had been carved by simple erosion from an original plane surface. In every direction the same features were in evidence. This surface may be a trace of the ancient erosion floor, originally lifted and warped to make the great Gobi basin, or it may be the result of subsequent planation, with this portion still uncovered by sediments. Or perhaps it has been stripped of a former sedimentary covering and somewhat dissected. Whatever the explanation, it is one of the finest exhibits of planation on crystalline rocks to be seen anywhere in the region. We named this upland surface the Mongolian Peneplane. (See Chapter XIX.)

The P'ang Kiang hollow

Our third camp was established near the telegraph station at P'ang Kiang, which stands in the midst of the fourth basin of sedimentary strata, on the border of a hollow which has been cut deeply enough to expose the edges of the beds (Figs. 10 and 11).

Although the locality promises fossils, diligent search in the time available failed to reveal any. During the season of 1923, however, a single fossil was found in this vicinity, proving that the P'ang Kiang beds are of Tertiary age. The topography of the basin introduces certain physiographic questions not hitherto presented. There is a post-mature, almost peneplaned upper

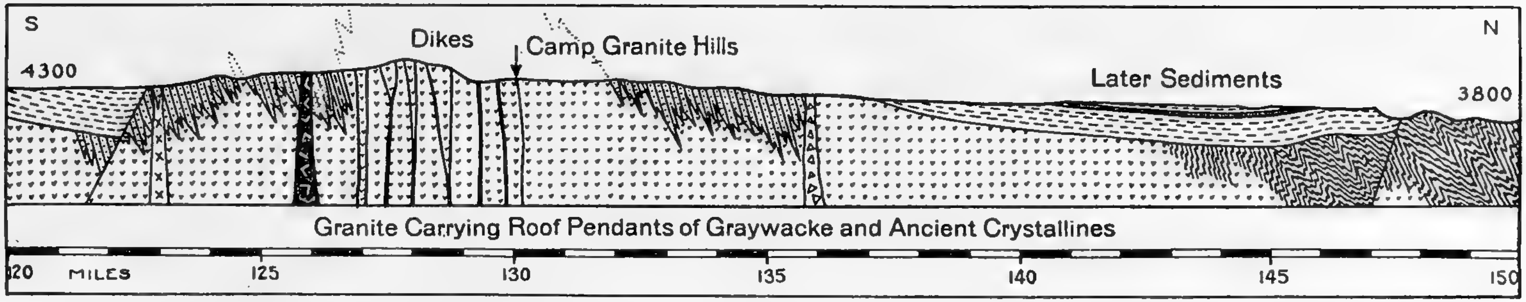


FIGURE 9.—Geologic section through low rolling country north of the Chakhar Mountains. The oldrock floor consists of granite carrying roof-pendants of graywacke, and, at mile 147, of schist. Two shallow basins of later sediments rest upon the oldrock floor.

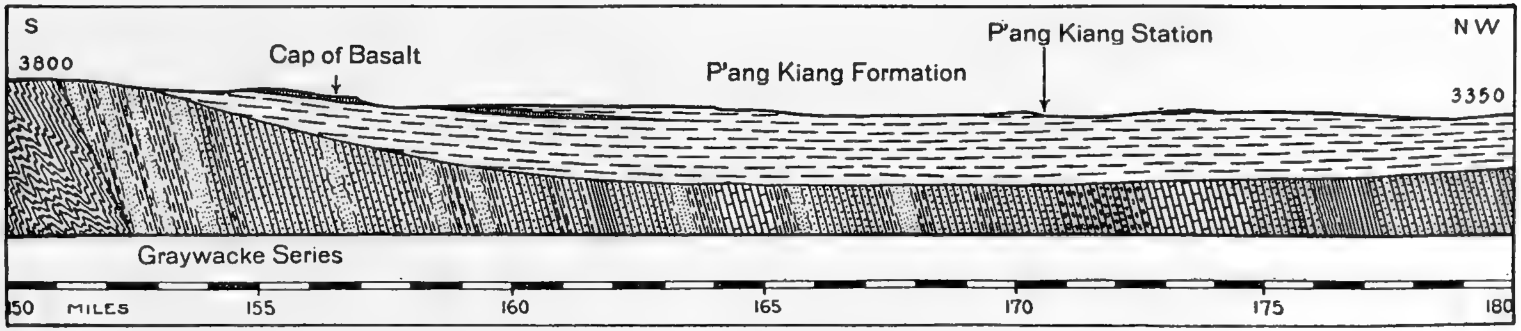


FIGURE 10.—Entering the P'ang Kiang basin, a typical large sediment basin or "gobi." (Compare with figure 11.)

surface on the sediments. It is clearly not the original surface of the deposits, but represents a long period of erosion, probably in some late Tertiary epoch. Later when the significance of the smooth upland came to be more fully recognized, we referred to it as the "Gobi erosion plane." The broad, undrained hollow, with an almost level floor, carved in this ancient plane, represents a definitely later stage in the local physiographic history. Similar relations were later recognized at many other places, so that the erosion features of this locality were selected as a type and referred to as the P'ang Kiang stage of dissection. It is essentially the latest important stage of erosion

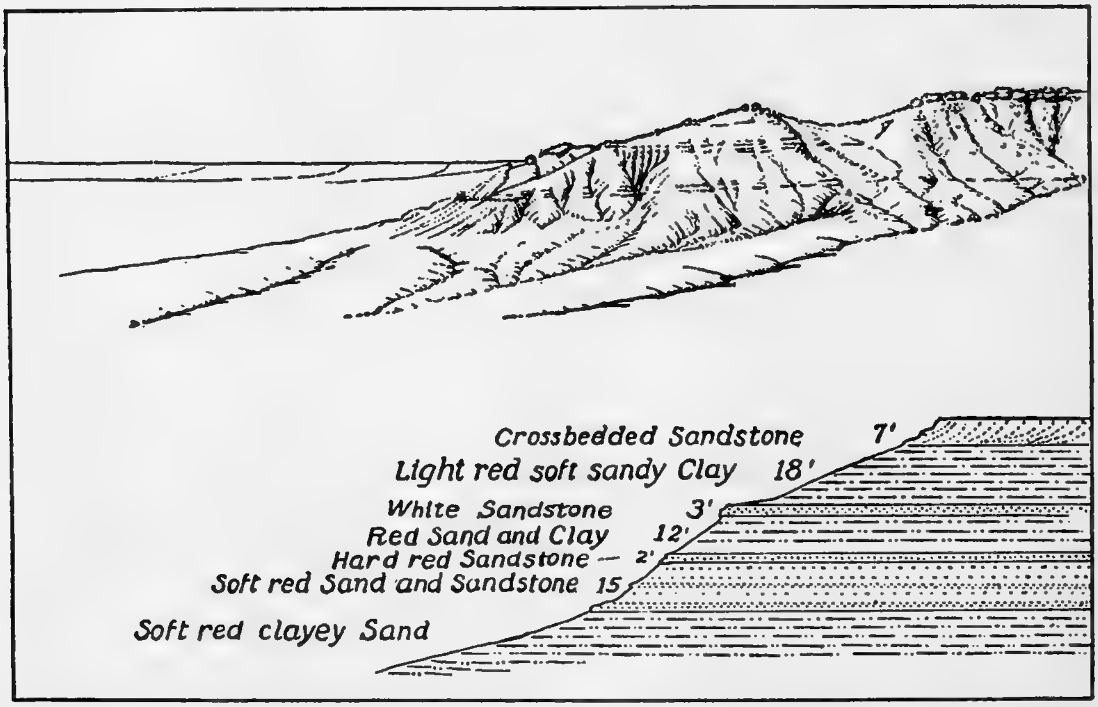


FIGURE 11.—Field sketch drawn southeast of the telegraph station at P'ang Kiang. The station lies in a large, undrained hollow eroded in the sands and clays, and the sketch shows the nearly horizontal sediments exposed in the wall of the hollow.

marking the dissection of the almost level surface presented by the sediment-basins. Even though the rock floor of the hollow is composed of comparatively soft sands and gravels, there is very little residuary soil. At most places there are only a few inches of residuary gravel or a few feet of shifting sand in the form of mounds.

At P'ang Kiang there is no way of determining how thick the deposits are. They lie almost flat, for they dip not more than four degrees from the horizontal, generally less (Fig. 11). The sediments are cross-bedded, and their structure seems to indicate that they were brought to their present position from the northwest rather than from the south. There are slight discrepancies of dip between the coarser upper beds and the lower fine, clayey beds, but this is not a marked feature. The whole structure is slightly deformed, or warped, since the strata of the east side of the valley dip gently to the east, while those of the west side dip even more gently to the west. It is, of course, entirely reasonable to believe that the sediments were formerly more extensive, and that they may have covered portions of the oldrock floor which are now bare. It is possible, also, that many of the last fifty miles of ground, where only small basins are indicated by the topography, have been stripped—the warpings that followed original deposition having exposed some of this ground to an erosion sufficiently deep to remove the whole cover.

The P'ang Kiang basin was the first to throw some light on the geologic history of the region, and although many other places furnished much more striking and conclusive evidence, none was more suggestive or helpful to the geologists of the Expedition.

P'ANG KIANG TO IREN DABASU

A few miles beyond P'ang Kiang we came, without a break in the topography, to the ancient floor (Fig. 12). The relations clearly show that at one time these Tertiary sediments must have formed a complete cover. The P'ang Kiang stage of erosion has stripped them from a small area, because here, either by warping or by faulting, the old floor is lifted higher than in the basin just crossed. It is probable, judging from the apparent dips of the strata, that the floor is brought up by faulting. This effect is repeated within ten miles. In both places small patches or strips of the ancient floor form outcrops at the surface, and are abruptly terminated and succeeded in each case by smooth gravel-covered ground having the characteristic appearance of simple, overlying sediments. After the last outcrop, at mile 197, the basin sediments appear once more and continue unbroken for sixty miles, to the telegraph station known as Erlien, or Iren Dabasu—the scene of one of the most important finds of the Expedition. (See Chapter XI.)

At miles 187, 197, and 217, three quite different types of rock are represented in outcrops, which are crossed by the trail after leaving P'ang Kiang. The first is a limestone belonging to old, much deformed units, whose age cannot be determined from the material itself but whose appearance is similar to limestones seen in Nan K'ou Pass, and similar also to limestones seen farther along on the traverse and regarded as of late pre-Cambrian age. The outcrops examined in the narrow strip exposed on the trail are not fossiliferous. The rocks dip steeply and are crumpled and sheared. The outcrop adjoins the sediment-basin along a comparatively straight marginal line, suggesting that it is brought up by faulting or by very abrupt flexure, although it is fully appreciated that original eminences in the old basement might present similar exposures after stripping. The ten-mile stretch from these limestone outcrops to mile 197 crosses a broad depression about one hundred and twenty-five feet deep, and on the next rise of ground, at mile 197, slates are exposed. Brief examination of these slates indicates that they were ancient sediments which have undergone considerable deformation. There is no possible way of determining either their age or their relation to other floor formations of the district, because the exposures are small, very obscure, and separated from the nearest outcrops of a different kind of oldrock by several miles of covered ground. They are similar, however, to many other slates noted on this traverse, most of them much farther along on the trail.

The third exposure of a type of rock different from the usual superficial sediments is located in the traverse between miles 217 and 229 (Fig. 13). In this stretch are numerous outcrops of limestone of dolomitic appearance. The rock has a peculiar porous structure, and there are traces of fossils, the nature of which was not determinable in the field. Structurally this rock is much simpler than that of the two outcrops previously described. It does not show deformation, metamorphic reorganization, or any of the complexities belonging to the most ancient types. It does not at all resemble the Palæozoic limestones which were encountered farther to the northwest. It has the structural appearance of a later time, but the evidence as to its exact age is not clear. Nothing resembling this formation had been seen previously along the journey of more than two hundred miles. Later on, we found patches of similar limestone interbedded in the basin sediments; we believe that they represent deposits formed in inland lakes and ponds.

The last appearance of the oldrock floor in this stretch from Kalgan to Iren Dabasu is a very small outcrop of slate, in the depression of Iren Dabasu at about mile 258 (Fig. 14). At this point a patch, very similar to that noted at mile 197, has been stripped by the erosion that has made the Iren Dabasu lowland. Its only significance comes from the evidence that it bears as to the shallowness of the basin itself, since the floor rocks are actually exposed at several places and form the northern edge of the sediment-basin. Doubtless the basin is deeper between these windows—i.e., between miles 197 and 258—but there is no way of measuring it.

Between mile 197 and Iren Dabasu at mile 260, we passed continuously over simple, nearly flat-lying sediments. The trail is on the upland to mile 238, where it descends abruptly into an undrained erosion lowland, representing the P'ang Kiang stage, and continues for seven miles in the hollow. At mile 245 the upland is reached again. Here a much smoother and much more gravelly surface, representing an erosion plane, extends to the Iren

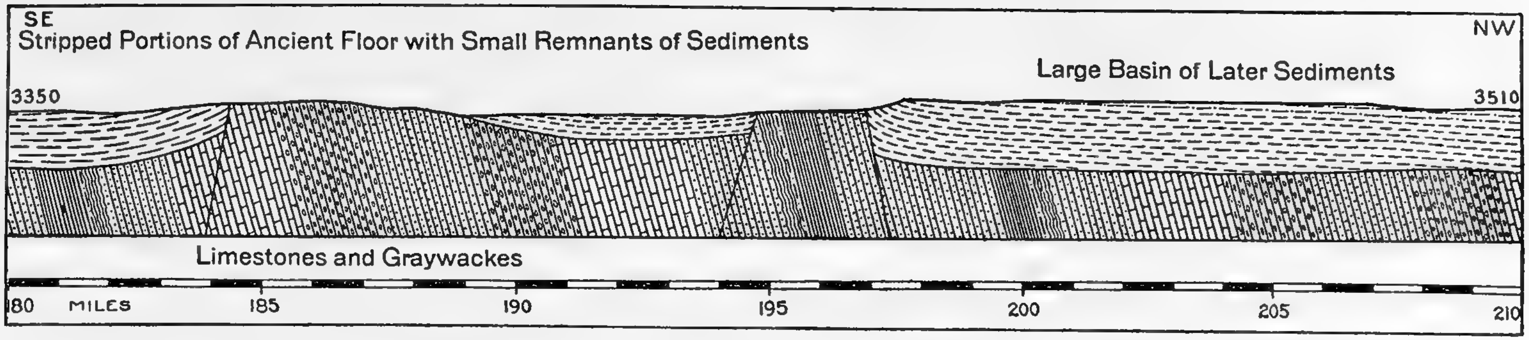


FIGURE 12.—The ending of the P'ang Kiang basin and the beginning of the basin of Irdin Manha and Iren Dabasu. The oldrock floor appears in two areas, due probably to faulting.

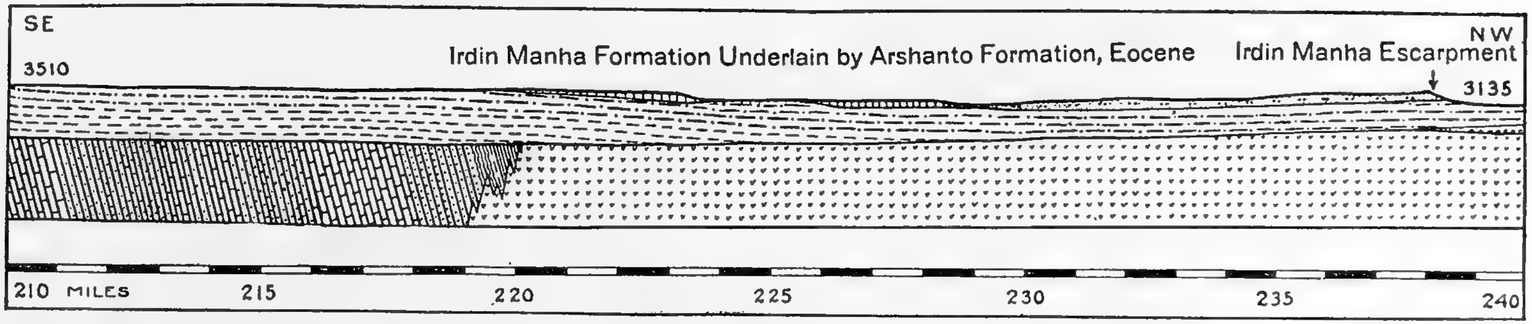


FIGURE 13.—Geologic section of part of the Irdin Manha basin. The areas of freshwater limestone are somewhat exaggerated. They represent shallow ponds or lakes that existed in Eocene time. The Irdin Manha escarpment is the beginning of a large, undrained erosion hollow, like the one at P'ang Kiang. (Compare with figures 99, 100 and 101, pages 198, 199, 200.)

Dabasu lowland, which begins at mile 255. These two different erosion forms, the level upland and the enclosed hollow, are especially well developed at Irdin Manha (Fig. 13).

Little of the topography, except in very minor ways, is constructional in origin. The smooth, almost level, gravel-covered surfaces that are encountered here and there, stretching away for miles, are strictly erosional forms, and are typical of the Gobi region. Since the Mongols call these great open areas of nearly level country "gobis," we chose the name "Gobi erosion plane" for the surface which we later were able to trace across nearly the whole desert region.

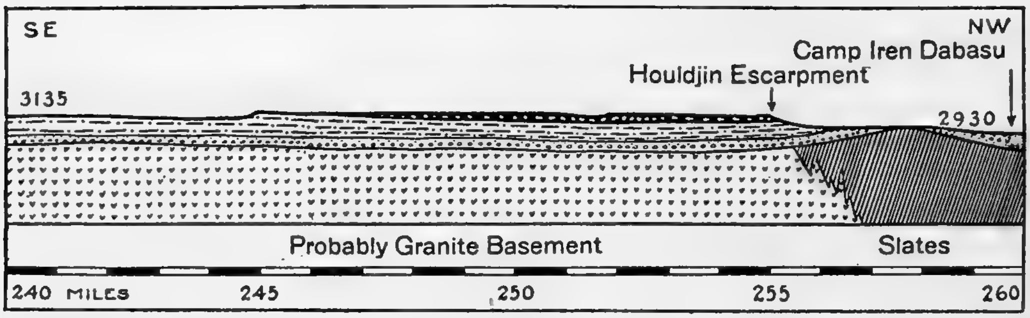


FIGURE 14.—Geologic section from Irdin Manha to Iren Dabasu, crossing a narrow strip of upland between two undrained hollows. At Iren Dabasu the lowest sediments are Cretaceous, resting directly upon the folded slates and followed by Eocene and Oligocene in the Houldjin escarpment. (See Chapter XI.)

All the landforms thus far mentioned are destructional. The most persistent constructional form consists of small hummocks or dunes of sand. They are, perhaps, the "tamarisk mounds" described by Huntington (1907, page 179). In some places they shift more or less, but in most cases they are small, very closely and irregularly placed, and owe their lodgment to shrubs and other small plant growths, which knit them together and give them some slight fixity. It is the shifting surface sands, however, that offer the greatest difficulty to the traveler and make it quite impossible in certain areas to depart far from the beaten trail. It is always easier to follow the trail where the disturbance caused by caravan travel enables the winds to keep the trail clear, so that the loose sands are, to a large degree, swept away. These surface accumulations are, in general, more numerous and troublesome in lowland areas represented by the P'ang Kiang dissection than on the Gobi erosion plane. The gravelly residue of the level upland seems to serve as a protection against the furnishing of sand for drifting, whereas the strata exposed in the walls of hollows of the P'ang Kiang stage are readily attacked, and sands from them are spread on the lowland and in places are swept over portions of the adjacent upland.

Nowhere in this whole traverse of 260 miles did we see any large drifting dunes, and nowhere is the constructional deposit more than a thin, superficial covering. No large features are controlled by it, and at no place is the accumulation, including both the soil mantle and the drifting cover, more than a film on the surface. Instead of being compelled to travel over great accumulations of loose sand, the Expedition actually traversed rock with only a few inches or a few feet of obscuring cover. To be sure, the floor itself is composed, in part, of simple and almost unconsolidated sediments, not very unlike the sands themselves; but they are, nevertheless, definite sedimentary formations and of varying age from place to place, quite different from one another, both in quality and in fossil content. The sandy and little consolidated character is responsible for the common failure of travelers to distinguish between loose sand and sedimentary rock formation.

Fully half the distance, however, is over a floor of much more complex rocks, and they also are exposed with little cover. The obscurity due to overlying soil is greatest in the first hundred miles, where some of the country has agricultural capacity—some, indeed, is cultivated by Chinese settlers, who are in this way encroaching upon Mongol territory (Plate VIII, B, page 48). The land could be farmed for a considerably greater distance northward, but by the time P'ang Kiang is reached, conditions have become too desert-like for agriculture, and the rock formations are too nearly bare, since here the wind is so successful in blowing away the finer débris that there is little development of soil mantle. This, therefore, is the edge of the Gobi Desert proper, which, as far as we have seen it, is essentially a rock desert.

The first fossils

At P'ang Kiang and again at Irdin Manha and Iren Dabasu (Plate X, A), the sedimentary formations are especially well exposed in the escarpments, where the succession of strata can be seen and intimately inspected. On the first traverse no fossils were found at the first two places, but upon arriving at the Houldjin escarpment above Iren Dabasu, at mile 255, numerous fragments of fossil mammal bones and teeth were found, while dinosaur bones were discovered at Iren Dabasu. Later, an extensive fauna was collected at Irdin Manha, and in the following season a single rodent jaw was brought to light at P'ang Kiang. The finds at Iren Dabasu were recognized at once as of very great importance, and on this account it was decided to spend additional time on this ground. Here the first local study was made. The results are set forth in special study No. 1 of Part III, "The Iren Dabasu Basin," constituting Chapter XI of this volume.

CHAPTER IV

FROM IREN DABASU TO URGA

ALTHOUGH sediments are extensively exposed at Iren Dabasu, the slate floor lies near the surface. One small outcrop is uncovered at the south side of the basin (Fig. 14), and a comparatively large area is exposed on the north border of the lake Iren Nor and near the Chinese telegraph station (Plate XXIII in pocket). The hollow is margined on the south by a scarp of sediments, and on the north by an abrupt ascent over crystalline rock to a nearly level erosion plane 200 feet above the lake (Fig. 15 and Plate XXIII in pocket). The trail over this northern edge passes across slates cut by numerous quartz veinlets like those in the bottom of the basin.

An inspection of the veins failed to show mineralization of any consequence. In spite of the abundance of vein quartz—a condition that was noted at many other places in the course of the summer—there is everywhere a surprisingly small amount of metallic content. Prospectors have dug pits here and there, and doubtless have made tests of the material for the precious metals. But we saw nothing that gave any encouragement to such a search, except the presence of the veins of quartz.

Farther to the east, the Iren Dabasu basin is bordered by intrusive granites which, with the slates, have been eroded to form the ancient floor (Plate XXIII in pocket). Within a mile of the north margin, on the way toward Urga, the slates are cut by basalts or traps (Specimen 35, A. M. 9724), which continue for about two miles (Fig. 15). The exact structural relations are not determinable, neither is it certain whether these rocks are intrusive or are in part surface flows. Some of the material has the aspect of surface flows, but in any case these rocks are much later than the slates with which they are associated. There is little evidence of deformation in the basalt, whereas the slates are considerably metamorphosed.

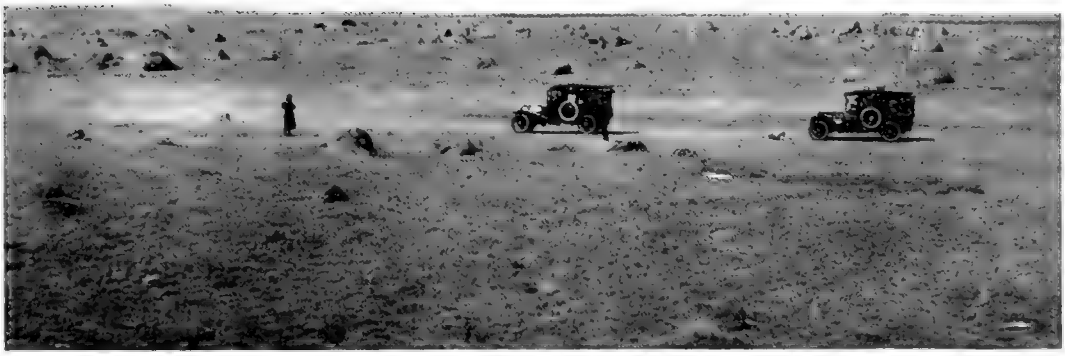
IREN DABASU TO CAMP JURASSIC

Six miles north of Iren Dabasu, at mile 267, the trail again descends to a basin-like area, smaller than Iren Dabasu but similar in superficial form

PLATE X.

A. IREN DABASU.

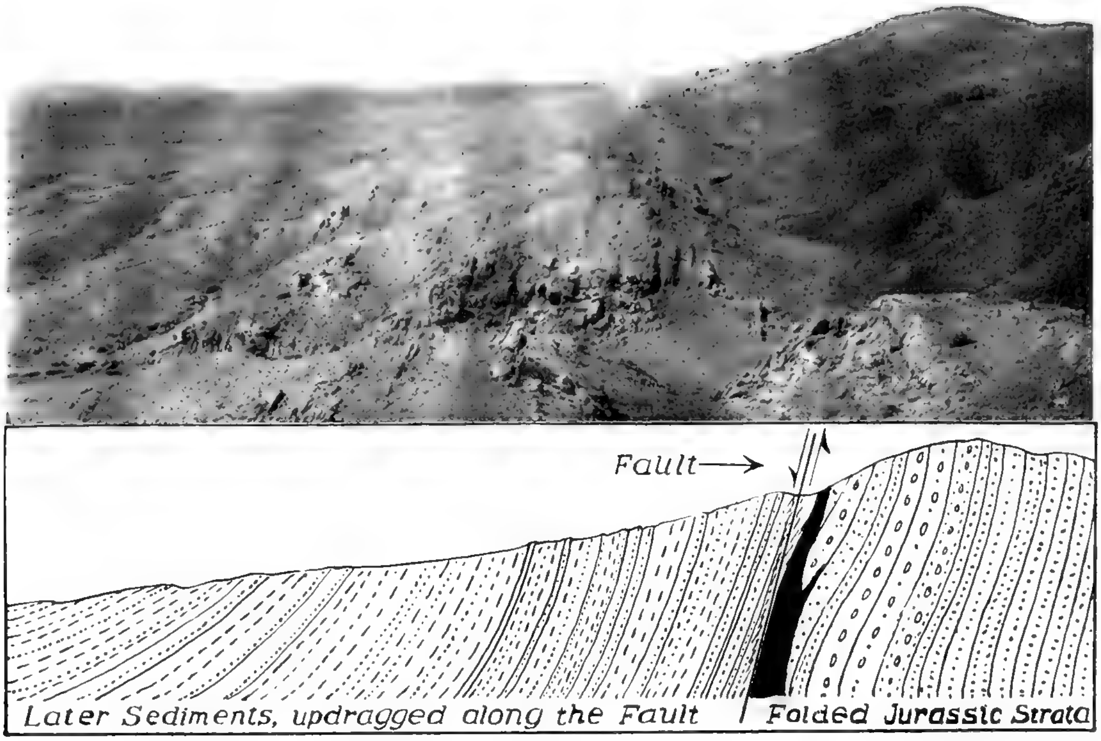
Dissected dinosaur beds at Iren Dabasu. The distant skyline is the Houldjin escarpment



B. RESIDUARY GRANITE BOWLDERS.

Bowlders of granite left as residuals on a level erosion surface of almost bare rock, along the Urga trail.

PLATE XI.



A. UPDRAGGED SANDSTONE BEDS AT CAMP JURASSIC.

B. MOUNT TUERIN.

Granite residuals on the lower slopes of Mount Tuerin. Irregular jointing controls weathering of the rock into peculiar shapes.

(Fig. 15). The floor is doubtless the same slate formation, but it is covered for several miles with later sediments which have been characteristically eroded into low, rounded bluffs and undrained hollows. The sediments continue to mile 272, where basalts are again encountered; then, a little way beyond, granites and syenites break through the slates and form the floor through a somewhat more rugged stretch of country.

At mile 275.8 there is a very striking outcrop of poikilitic syenite which displays a great many variations of composition and coarseness of grain. It probably represents, in part, the results of syntexis, and, in part, the end products of a differentiating magma. The chief local types include hornblende syenite, hornblende granites, and quartzose pegmatites. The locality bears a monument known as Kwei Ming Kwan, near which we noted a most complex group of variations in the syenitic rock. The dominant type is a hornblende syenite (Specimen 36, A. M. 9725), but there seems to be no real difference in age or origin between these and other varieties. Even the granite (Specimens 36 and 39, A.M. 9725 and 9728), from this same ground probably has essentially the same significance. At mile 278, there is granite porphyry (Specimen 40, A.M. 9729), and at mile 280, a very coarse granite (Specimen 41, A.M. 9730), both of which are probably only varietal expressions of the igneous activity of this peculiar area. In the Kwei Ming Kwan area, also, there are some older metamorphosed sediments, through which the syenites and granites have penetrated. The patches of these metamorphics now remaining seem to be merely portions of the roof into which the original igneous mass had advanced. They include a group of strongly veined argillites which probably have been tuffs (Specimens 37, 38, A. M. 9726 and 9727). Their peculiar greenish color and their structure suggest intermixture of ash. At mile 283, an ancient conglomerate is associated with the slates and tuffs. It carries bowlders of granite and many kinds of porphyry and may be a basal conglomerate (Specimen 42, A.M. 9731), but a detailed examination could not be made. There is evidence, at least in this locality, for an important structural break between two ancient series, and it is possible that this conglomerate represents the basal portion of the Nan K'ou series. We believe that the slates, as well as the limestones seen much farther back along the trail (miles 187 to 220), belong to the same series.

Argillite outcrops again at mile 286 and is cut by a very coarse hornblende granite, which is itself cut by dikes, and which continues for two miles or more. Slates or graywackes reappear at mile 289, and in a short distance are overlaid by sediments in a basin which extends from mile 289 to mile 302, a distance of 13 miles (Fig. 16). The slates of the margin are very badly deformed and stand in all attitudes, cut by granite porphyry and by basalt sills and dikes in great abundance (Specimen 46, A.M. 9735). The slates

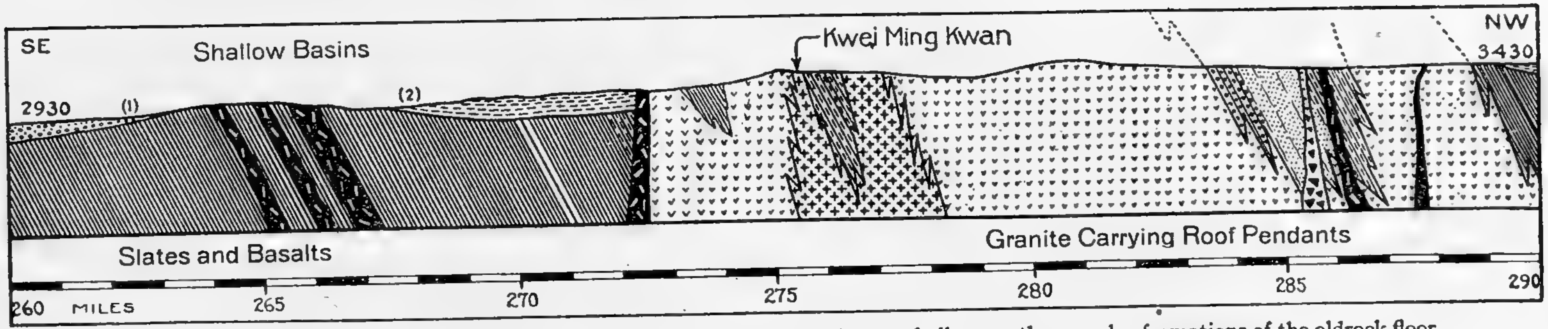


FIGURE 15.—Geologic section continued northward from Iren Dabasu almost wholly over the complex formations of the oldrock floor.

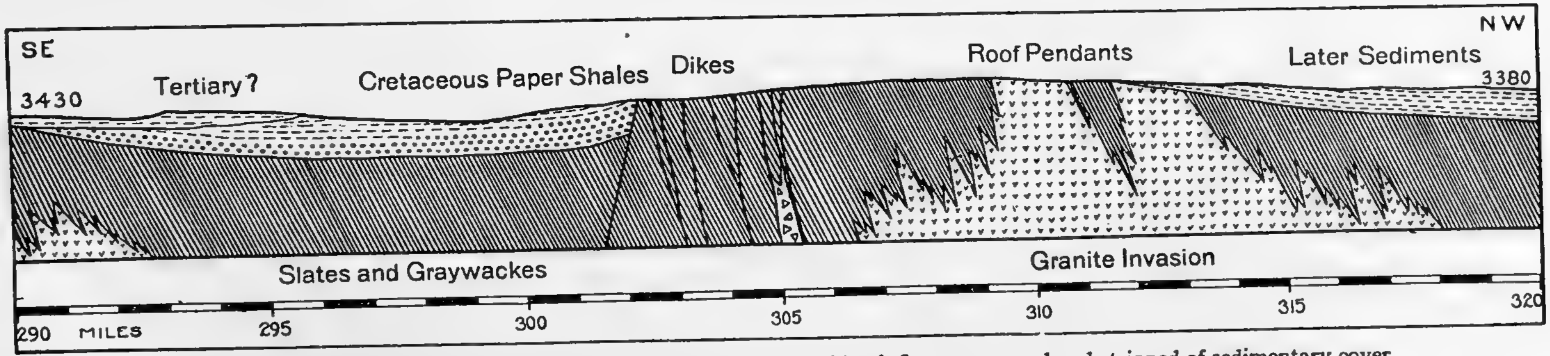


FIGURE 16.—Two sediment basins separated by an interval of the oldrock floor, upwarped and stripped of sedimentary cover.

themselves are variable in quality and extremely thin-bedded, but are well indurated. They are closely folded, and the strata stand vertically in places; but on the north side of the basin, where the slates form the surface for seven miles, the dips are chiefly to the north. The whole formation is undoubtedly very thick.

The sediments in the basin from mile 289 to mile 302 have a basal conglomerate of rather coarse quality on the north margin, at mile 302. At mile 296, there are red shales overlying a pebbly fresh-water limestone and sandstone, together with carbonaceous paper shales which contain scattered gypsum crystals. It was appreciated at once that the quality of these strata is unusual and that nothing quite like them had been seen. A rapid search was made for fossils, but none was found. Their possibilities in some respects were not fully understood until three months later, when we studied the Ondai Sair locality, north of the Altai Mountains. At Ondai Sair, exactly similar dark paper shales and red and gray sandstones furnished fossil insects, fishes, and plants, as well as dinosaur bones, by which they were determined to be of Lower Cretaceous age. The paper shales alone are so characteristic that there is really little uncertainty in correlating these deposits with the Lower Cretaceous of Ondai Sair. The sediments in this particular basin, between miles 289 and 302, are quite different in physical aspect from the Cretaceous strata which had already been identified at Iren Dabasu. A small salt pan lies in the bottom of the depression. The conglomerates at the base may indicate that basal beds of the Lower Cretaceous series are represented here. It is entirely possible, of course, that the higher red shales are of Tertiary age, but no satisfactory evidence of their age could be found.

This basin deserves additional study. It contains formations of the same type as those which elsewhere furnished a unique fauna, and probably would furnish also a valuable contribution if it could be inspected in detail. Undoubtedly important stratigraphic data could be gathered in a more extended investigation of the ground, from mile 289 to mile 302, especially by broadening the scope of the search to the east and west, within the basin. It is the only area noted on the Kalgan-Urga trail where the carbonaceous paper shales are developed in typical form. A week, instead of an hour, should have been devoted to this locality.

At mile 310, a very coarse granite, of almost binary composition, cut by pegmatite veins and quartz stringers, breaks through the slates and continues for two miles (Specimen 47, A.M. 9736). Since the ground slopes gently to the north, the granite gradually passes beneath a mantle of later sediments obscured by arkosic sand and many dunes. In a gulch at mile 320, however, we noted green clays, which are probably Tertiary beds (Fig. 17). The whole basin is very shallow and is terminated on the north, at mile 323, by slates similar to those seen before. From mile 325 the ground slopes rather rapidly between granite hills, northward toward Ude. An alaskite granite (Specimen 49, A.M. 9738), was gathered beside the trail. Probably a thin sediment, or at least an arkosic alluvium, occupies the bottom of the valley, in the midst of which stands a granite hill (Specimen 50, A.M. 9739), which marks the site of the station of Ude, now entirely deserted. From this point the trail follows the sandy wash of a stream bed with rugged valley sides of crystalline rock, probably granite, bowlders of which appear abundantly in the wash. No motor exists that can plow up this mixture of sand and cobbles without coming to a stop. And at mile 332, just where the heavy sand stops the car, the door-flap of a yurt opens, and a long-skirted Buriat official comes down, inspects the traveler's permit to enter Outer Mongolia, and invites him to pay a tax. In the hills on either hand sits an invisible garrison, ready to fire upon a car that is mad enough to try to run. The exaction may not be pleasant, but the strategic choice of a perfect motor trap is admirable.

Above the permit station, we cross a low divide to where, on the farther slopes, sedimentary strata overlie the granite. The road is smooth and gravelly for five miles, continuing down a gentle slope to a well at mile 341. Although there was no opportunity to determine the quality of this ground, the substantial nature of the material led us to believe that it may be older than Tertiary. The structure is basin-like, and is terminated abruptly on the north at mile 343, making a ten-mile stretch of sedimentary strata not very different from the others passed over in the last 75 miles. All of the sedimentary basins encountered in that day's run are small and shallow—none more than 10 or 12 miles across.

The country at Camp Snow Storm (mile 341) was covered with snow on the morning of May 8. This entailed some delay, but in the afternoon the clouds began to break, and a start was made. After a twenty-five mile run, however, the weather turned bad again, and a long-threatened storm broke in a furious blizzard. There was no alternative but to keep on as cautiously as possible, in the hope of driving through. By the time mile 373 was reached, the clouds had lifted again, and not only had the Expedition passed through the storm itself but it had come into ground where no snow had fallen. At this point we noticed a decided difference in the topography, which invited geological investigation to determine just what change of structure had taken place (Fig. 18). For some distance the storm, with its blinding snow, had obscured everything, but it was evident, at least, that a small basin had been crossed. Here a well gave opportunity for camp, and the party stopped at mile 374, in one of the most interesting structural areas to be found on the Urga trail.

Immediately after leaving Camp Snow Storm at mile 341, the trail leads over slates with a strike nearly east and west, and a dip south at an angle of

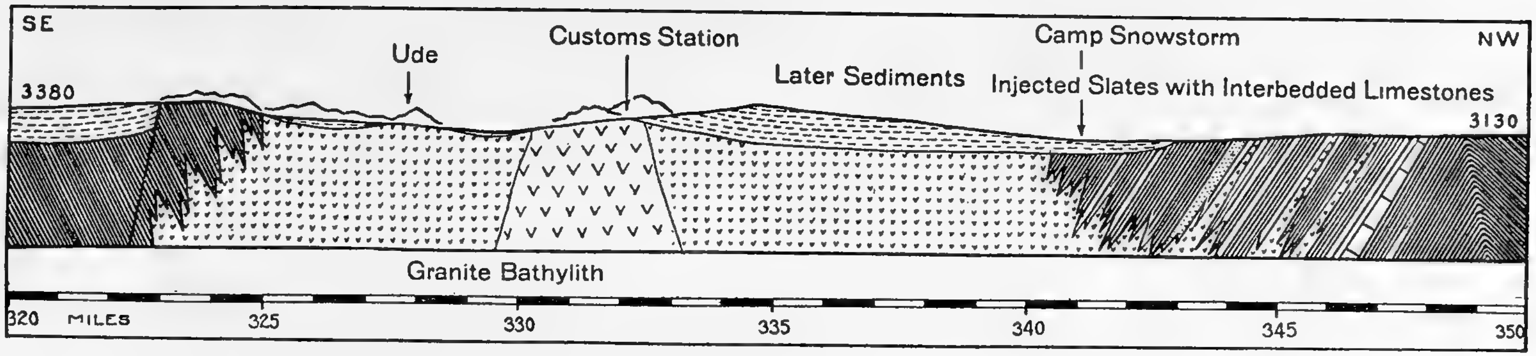


FIGURE 17.—The oldrock floor, locally covered by sediments, here consists chiefly of granite which invades a great series of slates.

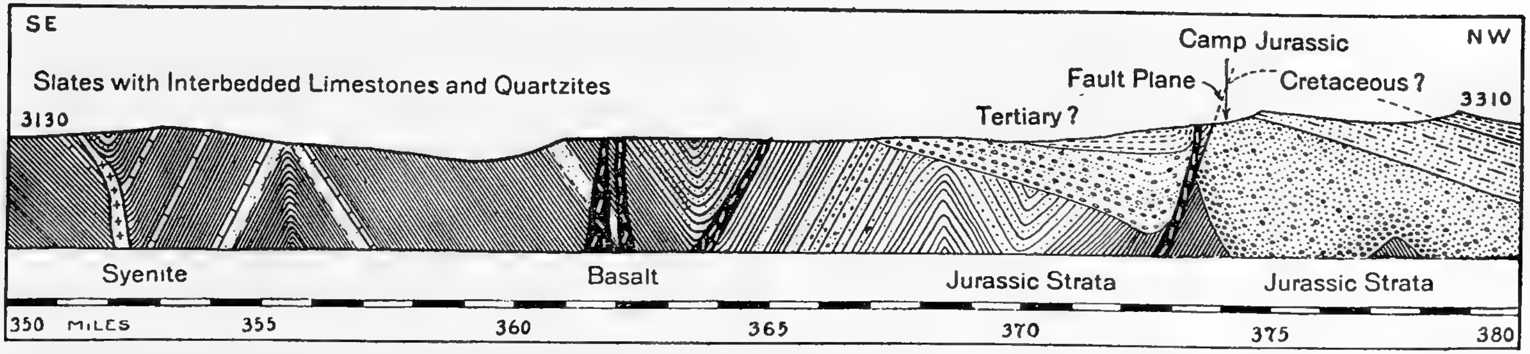


FIGURE 18.—Geologic section across a wide area of complex oldrocks, succeeded by an exceptionally good display of Jurassic and later sediments. (Compare with Plate XI, A.)

about 60 degrees. There are many interbedded limestone and quartzite layers, but the most striking feature is the occurrence of great numbers of granite sills, which penetrate the slates. Weathering and erosion have left residuary bowlders of granite scattered along the course of the sills, as though they were the ruins of long, low masonry walls built upon the marvelously level surface of the desert. No more splendid exhibit of planation across different types of rock has been seen in the whole of Mongolia than is shown in this stretch of ground. From mile 343 to mile 353, folded slates which stand nearly on edge are interbedded with limestones and quartzites. They are associated with granite sills and all are planed off so perfectly that one can drive almost anywhere by motor. This kind of ground continues for twenty-four miles.

It is clear that the formations are folded, but the structure could not be determined in greater detail, because of the rapidity of travel. Possibly the limestones furnish evidence of the age of these beds, but no fossils were found in them. In the northerly half of this stretch of ground the limestone beds are much more numerous, and there is some variety in the quality of associated slates and sandstone. Northward from mile 355 there is a valley-like depression in which the character of the material is less easily made out, but the slates dominate, with some graywacke and a few quartzite beds.

At mile 362 one of the most striking features seen thus far in the traverse is represented by a volcanic blowout, which forms buttes and minor ridges bursting up through the slates. The rock is an olivine basalt (Specimen 66, A.M. 9755). North of this blowout the ground carries more graywacke and less slate, becomes pebbly, and obscures the relation to the slates and limestones farther south. At mile 367, conglomerates, the like of which we had not yet seen in our traverse, lie nearly flat beside the trail. Observation of these beds was interrupted by the snowstorm, and the point at which change to later sediments takes place was not accurately determined. Their presence, however, was not long in doubt, because they were found again at Camp Jurassic, mile 374, on the north edge of the small basin which occupies the ground from miles 370 to 374.

The belt of slates, from mile 343 to mile 367, deserves more careful inspection than could be given. There must be an immense thickness, perhaps 15,000 to 20,000 feet. Their variation in character, the amount of deformation they have undergone, the strikingly abundant intrusives in the form of sills, and the numerous limestone interbeds, are prominent features. Probably more than a hundred granite sills were seen in this stretch of ground, all of them intersecting the strata in a clean-cut, definite fashion, instead of impregnating or absorbing or markedly metamorphosing the country rock. There are many quartz veins and occasional jaspery bands. Doubtless these latter are related genetically to the intrusives in some way. The slates impressed us as having finer grain and a better slaty structure than most of the slates subsequently encountered farther north. Indeed, the relation between these fissile slates and the argillites and graywackes farther north is one of the questions not satisfactorily settled. They may be equivalent, but, if so, there is a marked change in lithologic quality.

The structural relations at Camp Jurassic

Because the physiographic features showed that a change in structure had been reached at mile 374, camp was made there on the evening of May 8, so as to give an opportunity for more detailed inspection of the ground (Fig. 18). The strata which occupy the narrow basin extending from mile 370 to mile 374 have been turned on edge by drag against the older formations. The plane of movement could be readily located (Plate XI, A). In the distance, in line with this fault, several small volcanic cones were seen. The strata thus turned on edge are sandstones belonging to the later sediments; their exact age is undetermined, but, judging from their petrographic character and condition, they may belong to the Tertiary series.

Special interest centered in the formations standing almost vertically in the uplifted block against which these later beds are faulted. The older strata are comparatively hard sandstones in great variety, and are devoid of fossils except for scanty and obscure plant remains. The agencies of weathering and erosion have carved them into fantastic shapes. The structure and history of the rocks seem to be consistent with what was expected of the younger strata belonging to the floor formations; there is no metamorphism, and the beds are simply folded. In China, rocks which in all essential respects resemble these are regarded as of Jurassic age, and the same correlation was assumed for this locality. Later, at three other places, strata were found, similar in composition, structural relation, and history, and apparently consistent with the assumption that they are all of Jurassic or mid-Mesozoic age.

The area is more significant than it at first appears to be. Here one can see that the basins carrying the later sediments, such as had been crossed repeatedly in the traverse from Kalgan, may have originated, in part, by deformation of comparatively recent date, for in places the strata themselves are turned up on edge, indicating that some of the deformation is younger than the sediments. The making or deepening of basins, therefore, probably was a long-continued and oft-repeated process.

Within two miles the entire exposure of the steep-standing sandstones of the floor is crossed, and younger overlying beds appear again. Evidently there is an uplifted area adjacent to the down-dropped one. The erosion surface, representing the original floor, has been thrown into broad arches and troughs by gentle warping, but there are sharp flexures and faults along certain marginal lines. It is apparent, also, that volcanic activity found vent along some of these lines of weakness. An extensive igneous accumulation, both of lava and of tuffaceous material, is associated with the overlying deposits. There are evidences of volcanism also within the supposed Jurassic area, but the relations there are obscure.

The supposed Jurassic strata strike N. 60° E., and dip steeply north. There is a marked angular unconformity between them and the beds coming in above (Figs. 18 and 19). The area exposing the Jurassic strata is the center of a breached, dome-like uplift, with annular valleys, dip slopes, hogbacks, and the other erosion-forms characteristic of a dissected dome of sedimentary strata (Fig. 122, page 281).

On the whole, this locality was the most illuminating in the matter of dynamic history and structural relations of any thus far seen in the Mongolian region. There is definite evidence of the succession of sets of strata and of their relation to deformation and igneous activity. Here one can see the youngest strata that belong to the ancient floor, and this is the first place where strata suggesting Jurassic age had thus far been seen. It is a clear case of late faulting, and volcanism seems to be structurally related to that weakness. It shows that there is a great unconformity between the Jurassic strata of the floor and the so-called later sediments. It seems also to carry evidence of an important break in the midst of later sediments, particularly in the ground forming the north side of this dome. Apparently there are three important series here, one of Mesozoic age belonging to the old floor; another, the first series of sandstones above the unconformity, lying on that floor; and a still younger series, including the topmost beds.

At the time these features were first seen, it was not fully appreciated that the structural elements of this locality are representative of the most fundamental structure of the Gobi region. Although not fully proved at the time, it appears certain from later developments in adjacent regions that the two sedimentary members at Camp Jurassic, overlying the eroded edges of the so-called Jurassic strata forming the floor, include a Cretaceous series and, after a slight unconformity, a series of Tertiary strata of simpler history. This splendid structural exhibit presents a good opportunity for working out in much greater detail the sedimentary history of the region, and warrants the recommendation that this area be given a more extended investigation. The strata of these different types are well enough exposed to allow a comparatively complete column to be constructed, as there must be at least 3,000 feet exposed in the area, a large portion standing almost on edge. Here, an area that could be extended so as to include the basin to the north deserves mapping, as well as a structural and palæontologic study.

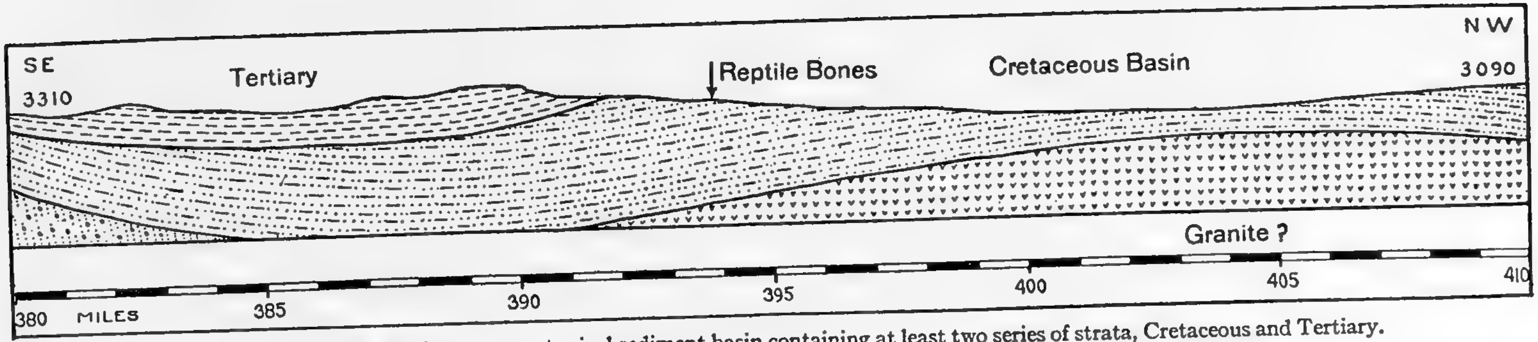


FIGURE 19.—Geologic section across a typical sediment basin containing at least two series of strata, Cretaceous and Tertiary.

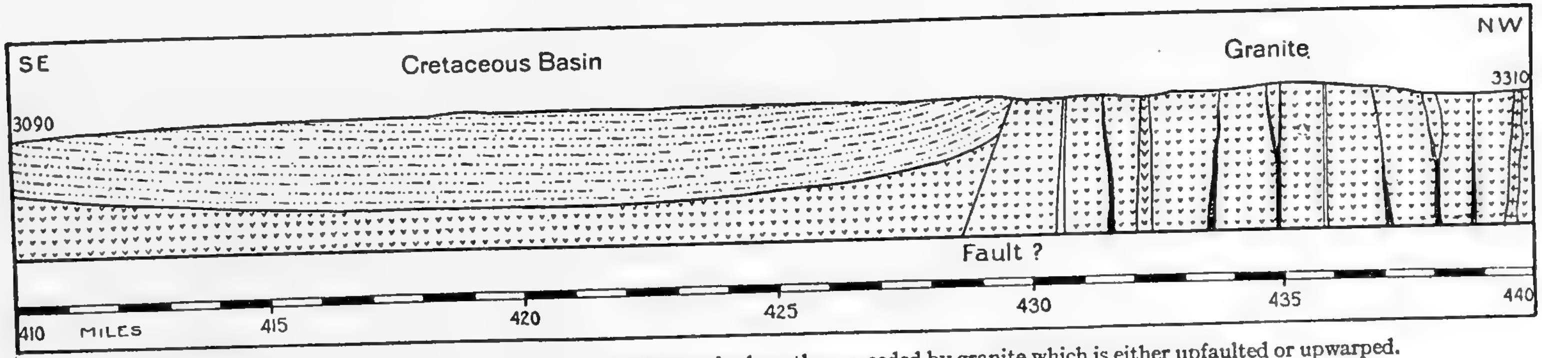


FIGURE 20.—The broad basin of Cretaceous sediments is abruptly succeeded by granite which is either upfaulted or upwarped.

CAMP JURASSIC TO MOUNT TUERIN

The "Camp Jurassic" dome proved to be a very limited one. It is dissected in perfectly typical form, and from the higher eminences one can follow the hogback border from the south side eastward and northeastward until it curves back to the west again, completely closing that end of the uplift.

For a distance of little less than a mile, the trail crosses steeply upturned sandstone beds supposed to be of Jurassic age (Fig. 17). The thickness represented is at least 3,000 feet, with neither the top nor the bottom exposed. At mile 375, a new series of sandstone beds appears unconformably on the upturned edges of the Jurassic strata, dipping much more gently northward. They clearly belong to the so-called later sediments of the desert region, although no fossils were found to indicate their age.

This series continues as a foundation rock for four miles to an escarpment and divide at mile 379, where the red-colored strata are made up largely of basalt bowlders and smaller fragments of igneous material, which, in a general way, strongly resembles the material noted on the south side of the dome. It is much more loose in structure than either of the formations occupying the center of the dome, and, although the structural relations are not quite clear, the general dips along the trail indicate that there is an unconformity beneath this formation also (Fig. 18).

The upper series of sediments, beginning with the red volcanic débris, continues for thirteen miles and is succeeded by sandy sediments of considerable variety (Fig. 19). Over this stretch of ground the trail is gravel-covered, and although there is considerable difference of relief the sediments throughout seem to be of the same simple type. At mile 392, more substantial rocks form the floor, and we judge that the previously encountered sandstone series again comes to the surface. This type continues from mile 392 to mile 429, and constitutes one of the longest stretches of continuous basin structure thus far seen (Fig. 20). The trail for many miles over the sandstone beds is remarkably smooth, and furnishes an excellent road for travel. The only difficult places are where the sandy channels of dry water courses cross the trail. Over most of the ground there are no outcrops, and the country is a typical open plains area such as the Mongols call a "gobi."

A significant find was made in the banks of a small stream at mile 394, where several fragments of reptile bones were recovered. These reptile bones and the somewhat disturbed and indurated beds suggest Cretaceous age. These beds we judged to be continuous with the middle member of the Camp Jurassic dome. It is clear that the ground is all sedimentary, and is a direct continuation of the sedimentary series exposed to better advantage in the first few miles of the trail; but from this point to the northern limits of the basin, at mile 430, no additional exposures of consequence were seen. It is quite possible, however, that much better conditions for inspection might be found either to the east or to the west of the trail, and if a point could be found where the ground is more successfully dissected, this basin would furnish an exceptionally good field for further investigation and collecting. This is especially true if our interpretation of the Cretaceous expanse is correct as represented on the sections, for it is one of the longest stretches of supposed Cretaceous ground encountered in the summer's investigation.

At the northern edge of the basin, there is a sharp transition to granite (Specimen 70, A.M. 9759). There is no indication of the structural causes of this change, but we have chosen to represent it as a fault. It is possible, of course, that it is simple warping which brings the floor of the basin gradually to the surface, but the effect is the same. For the next eleven miles along the trail the rock floor is virtually bare. It is formed of coarse granites which display considerable variety within the mass. The granites are cut by many dikes, chiefly syenite, pegmatite, and granite porphyry, while a few are latite or melaphyre (Specimens 71, 73, A.M. 9760, 9762). There are many residuary outcrops and bowlders (Plate X, B), around which is strewn a loose arkosic sand, resulting from disintegration of the granite. The floor is splendidly planed, and the profile followed over the sediments for the last twenty miles continues over the granites without noticeable difference of relief (Plate XII, A). It is not likely, of course, that the planations of both the crystallines and the sediments have been accomplished together. It is more probable that the granite profile represents an older peneplane which has been stripped and additionally planed during the later stages of erosion that have affected the adjacent sediments. It is most impressive to find repeatedly such perfect conformity of profile on adjacent areas of strikingly different quality of rock.

This is one of the largest stretches of granite that we saw in the Gobi region. The rock is a very coarse-grained, uniform type, not at all gneissic or gneissoid in structure. It has not been much metamorphosed, but it is closely associated with gneisses of general granitic composition, which have had a much more complicated history, and it must cut these gneisses as an invading intrusive. We were later to discover evidence that a great granite bathylith underlies central Mongolia, for we found that repeatedly this same general type of granite cuts through older formations and constitutes the floor for considerable distances. This granite area doubtless belongs to the same unit.

From mile 441 to mile 444, the ground is covered and smooth and has all the outward appearance of being sedimentary. It is apparently a very small, shallow basin in the granite, in which a thin cover of sediments is preserved (Fig. 21). From mile 444 to mile 448, the floor is formed of granite gneisses representing very much older formations, the precise relations of which are unknown, but they have the appearance of being the most ancient of any thus far encountered along the trail (Specimen 74, A.M. 9763). In most places where gneisses and other ancient crystallines were seen along the Urga trail, the strike is nearly east and west. In this particular local stretch the strike is nearly north and south, with a dip to the west.

From mile 448, basin sediments lie on the gneisses for seven miles; but at mile 455, the floor emerges, either by faulting or warping, and is represented by a complex series of gneisses, crystalline limestones, schists, and granite intrusions cut by black dikes. The structure is confused; the rocks are all somewhat metamorphosed (except the igneous intrusions) and must belong to some very ancient type (Specimens 78, 79, 80, 81, A.M. 9767, 9768, 9769, 9770). The limestones are strictly interbedded with the gneisses and schists, but the whole series is cut in a complicated way by granites, probably offshoots from the bathylith, and by dikes that are of later date. These dikes exhibit considerable variety, the most important types being syenite and granite porphyries. The original sedimentary series must have included sandstones, shales, and limestones which now appear as schists of various sorts. The origin of the gneisses is less certain, but in part, at least, they are likewise ancient, injected sediments.

This type of geological structure continues for another ten miles and more, and presents the most complicated structural unit yet seen in the Gobi region. It is much too complex a problem to be worked out in satisfactory detail in so hurried a reconnaissance. The chief items characterizing this belt up to mile 468 are as follows: a red mica schist, very thick; massive crystalline limestone, one belt half a mile in width, with numerous smaller belts; several beds of dense quartzite; and thick graywacke schists. These are intricately cut by granite and granite porphyries. There is not much intimate injection or impregnation, in spite of the abundance of igneous material. The igneous members, with their differentiation products and different stages of development, may all belong to a single magmatic source.

The ancient metamorphics, represented by specimens 83, 84, 85, etc. (A.M. 9772, 9773, 9774, etc.), are of special interest. They have a more complicated structural habit than the Nan K'ou series as recognized in China, but correspond very well indeed to the descriptions of the Wu T'ai system of Bailey Willis as determined in China. The Wu T'ai system includes limestones, phyllites, green and black schists, and sheared greenstones. The best that can be said, of course, is that this ancient formation, from mile 455 to mile 469, is similar in all essential respects to the Wu T'ai system. We doubtless have in the floor of the Gobi representatives of the same age and of the same general petrographic character as are found in China.

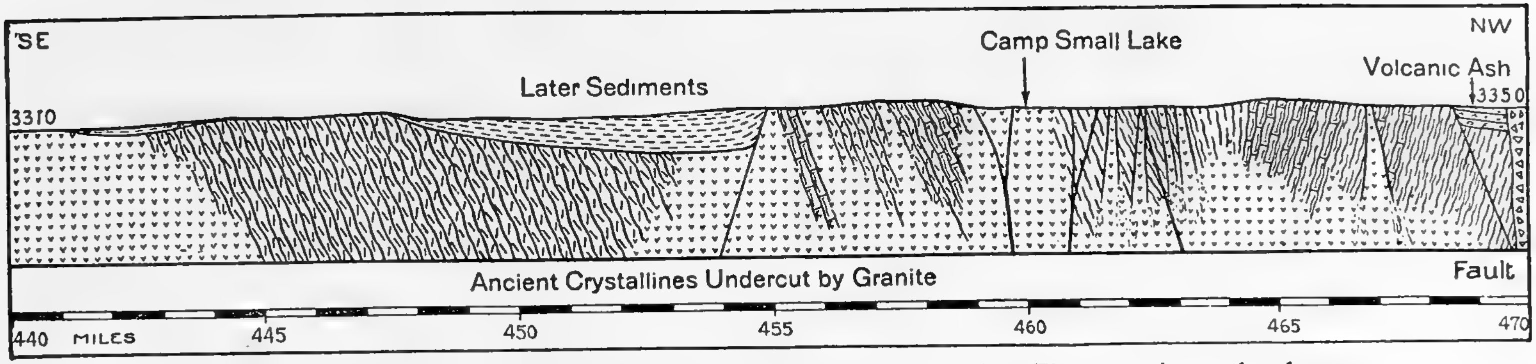


FIGURE 21.—Gneisses and crystalline limestones, undercut and injected by granite. The country is smooth and open.

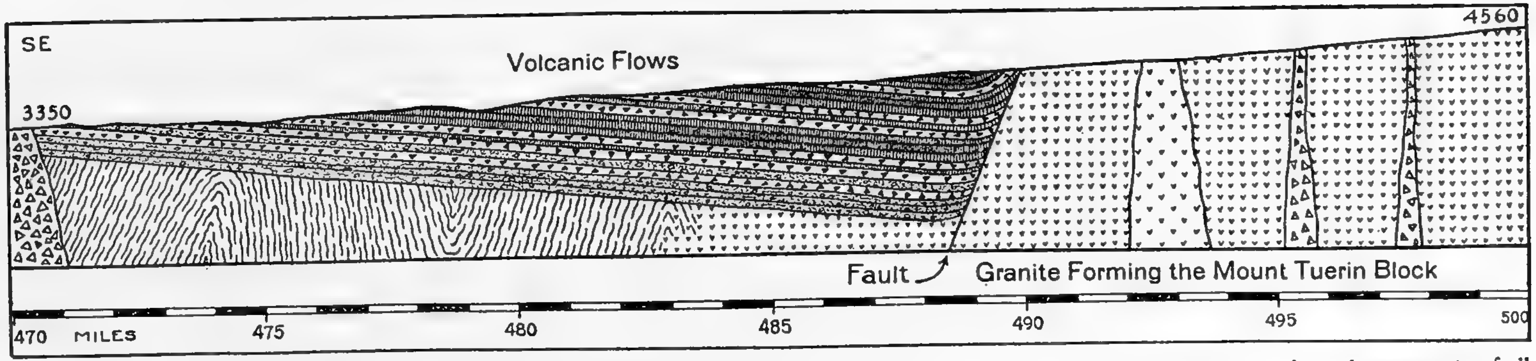


FIGURE 22.—A basin carrying an unusually large series of volcanic flows. The thickness of each individual flow is 20 to 40 feet; the aggregate of all the flows is probably at least 400 feet. The thickness is exaggerated in the section.

At mile 468.5, a sudden, complete change in formations takes place, probably due to faulting; the floor for a short distance is composed of sandstones similar to those seen at Camp Jurassic. It is entirely possible that they are Jurassic strata. They are cut by granite porphyry and are overlaid by rhyolite flows and ash-beds of great variety, in which are a few sills (Specimen 89, A.M. 9778). The igneous rocks continue for several miles, dipping gently northward, and constitute a great series of volcanic flows of both acid and basic type (Fig. 22). Some of the flows are very pumiceous (Specimen 90, A.M. 9779), and exhibit beautiful minor variations of petrographic quality. The chief types are interbedded rhyolites and basalts, and each type is repeated several times. Some of the vesicular basalts (Specimens 91 and 93, A.M. 9780, 9782), are crowded with amygdules of agate and chalcedony, and the ground is literally strewn with millions upon millions of these pebbles, known as "Gobi stones," so that the trail looks as if it were studded with jewels. The series continues for twenty miles, dipping gently northward, but is terminated abruptly along the north side of a range of low hills consisting of rhyolite breccias and basaltic tuffs. Probably the termination is against a fault, and the basin has dropped down at this edge against the granite. Here the strata are structurally more obscure, perhaps because of the deformation. There is apparently no way of accounting for the change to granite without such displacement, nor is there any way of telling the age of the formations. Although lava flows are common elsewhere, at no other place has so remarkable a series been seen in the Gobi region.

The succession at this place could be worked out in great detail. In passing over the ground so rapidly it was not possible to detect all the units, but it is clear that the earlier and lower members are chiefly rhyolites with rhyolite porphyry sills, rhyolitic ash, and pumiceous rhyolite, whereas the topmost flows are chiefly basalts with only an occasional rhyolite flow or rhyolitic sill. The middle members are more mixed than either extreme, and carry both rhyolites and basalts. The total thickness of these rocks is certainly over 500 feet, and probably exceeds 1,000 feet.

The granites of Mount Tuerin

At mile 490, the trail enters on a stretch of granite, which continues uninterruptedly to Mount Tuerin, a distance of twelve miles (Fig. 23). Some of the ground is covered with débris, but the bedrock outcrops at frequent intervals, broken only by later injections in the form of dikes, chiefly of several varieties of granite porphyry (Specimens 97, 98, A.M. 9786, 9787). This is the granite of Mount Tuerin, which is a residuary remnant of a large boss and is undoubtedly a part of the great Mongolian bathylith. The rock is a hornblende granite, and is fairly uniform in the central portion of the mass.

There are many other varieties of granite, however, especially on the north side of the mountain. The whole area, therefore, is a granite complex, but there is no indication of great differences of history in its various parts. Its age relations are unknown, because nowhere along the trail could we see its structural relations with other rocks of known age. On the south the contact is formed by a fault, and on the north the granite is overlaid by later sediments.

Mount Tuerin is a conspicuous landmark, visible for a great distance from every direction as it looms to exaggerated height when seen across the arid plain (Plate XI, B). It is a splendid example of a residuary remnant of a very much larger mass, most of which has been worn away to a remarkably smooth erosion plane. The central portion of the remnant is rugged and craggy, and difficult to cross with such an expedition as ours.

The west base of the mountain has been chosen as the site for a lamasery, where about 500 lamas, or priests of Buddha, live. This is by all means the most pretentious establishment which we saw along the Urga trail. Here, in 1921, the Chinese made one of their last stands in their retreat across Mongolia, after being driven out of Urga by the combined Russian and Mongolian forces. A year later, at the time of our visit, the ground was still strewn with relics of that encounter.

In the peculiar mirage-producing atmosphere of the Gobi, Mount Tuerin presents a more striking appearance at a distance of twenty-five miles than close at hand. The effect is increased by the crags and pinnacles left by the weathering of a jointed granite. The master joints fall roughly into a system, and the principal weathering and erosion features follow these same lines. The most marked set have a trend N. 60° E. There are prominent cross-fracture joints also, which divide the rock masses very unequally. As a result there are many overhanging and poorly balanced residuary blocks (Plate XI, B). There are also many small valleys and grassy slopes which add immensely to the beauty and picturesqueness of the place, and add, too, no doubt, to the interest it holds for the Mongol people. One can readily see the appropriateness of locating a great lamasery at the foot of this mountain. So unusual is the appearance of Mount Tuerin against the surrounding country that it seems to the Mongols to be marked by nature as a place deserving special reverence.

Mount Tuerin was the first rendezvous for the Expedition. It was here that the motors overtook the caravan and received from it their first supplies, separating again for the next lap of the journey. Camp was pitched in a grassy valley of the mountainside, on one of the most attractive sites of the whole summer; but the geology, despite the picturesqueness of the outstanding features, is too simple to require extended study. The Expedition, therefore, moved on toward Urga after only a day or two of local inspection. For the first four or five miles the same hornblende granite continues. It is a coarse-grained type with miarolitic structure, slightly pegmatitic in tendency, but much less so than is usual in a large granite mass. Under weathering, the rock tends to stain with some black coloring matter, probably oxide of manganese.

MOUNT TUERIN TO BOLKUK GOL

Beyond mile 509, new types of granite were encountered, quite different in physical appearance from the Mount Tuerin type. The relations of one to the other were not clearly made out, but probably the new types cut the mountain mass as later intrusives (Specimens 102, 103, 104, A.M. 9791, 9792, 9793). Farther on the complexity is increased by the presence of still other intrusives, while some of the preceding varieties are repeated. The granite complex continues to mile 524, giving thus a section of thirty-four miles from mile 490, where the unit was first observed. This is the longest single stretch of granite encountered on the Urga trail.

It is not possible to determine exactly where the granite floor ends and the new change begins, but at about mile 524, after crossing a small stream, the country opens appreciably (Figs. 23 and 24). The ground, which has been comparatively uneven, with a good many outcrops and residuary knobs, gives place to smooth, level country, and the arkosic character of the soil gives place to gravel of the sort usually accompanying the later sediments. The topography is more open, with broad, gentle sweeps and without eminences of any kind. As there are few outcrops it is not possible to determine much regarding the character of the underlying material, but it is evident from every feature that a decided change has taken place. This has come gradually, probably by the downwarping of the old floor, so that overlying sediments are preserved, and arkosic disintegration material is mixed with sedimentary residue in a sort of transition zone of surface cover. Farther along, outcrops of sediments are exposed. This type of country continues for nearly fifty miles and constitutes the largest continuous basin thus far crossed by the Expedition. There is no clue to the age of these sediments or to the details of their structure. They are more completely covered than usual, because the traverse has now entered the grassland country, where much larger amounts of soil are held than is the case in the desert.

There is here little similarity to the barrenness seen farther to the south. At this time of year, early May, we saw only the dried remains of last year's vegetation, but over long stretches it must have stood two feet high in the growing season. The district is a typical grazing country, with here and there a lake furnishing ample water for stock. Whether the lakes carry water

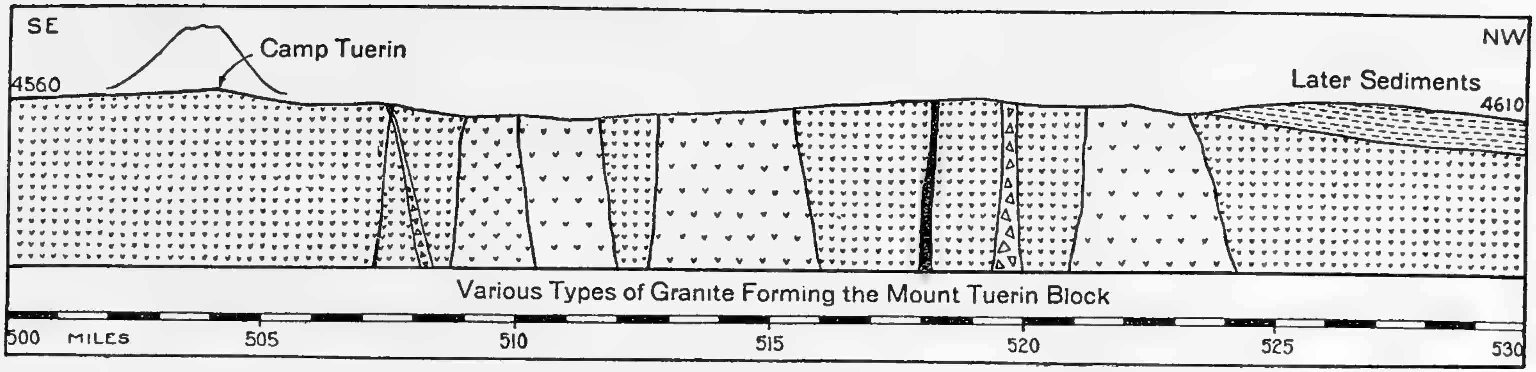


FIGURE 23.—The erosion plane girdling Mount Tuerin and beveling the complex granite massif. A view in the mountain is shown in Plate XI, B.

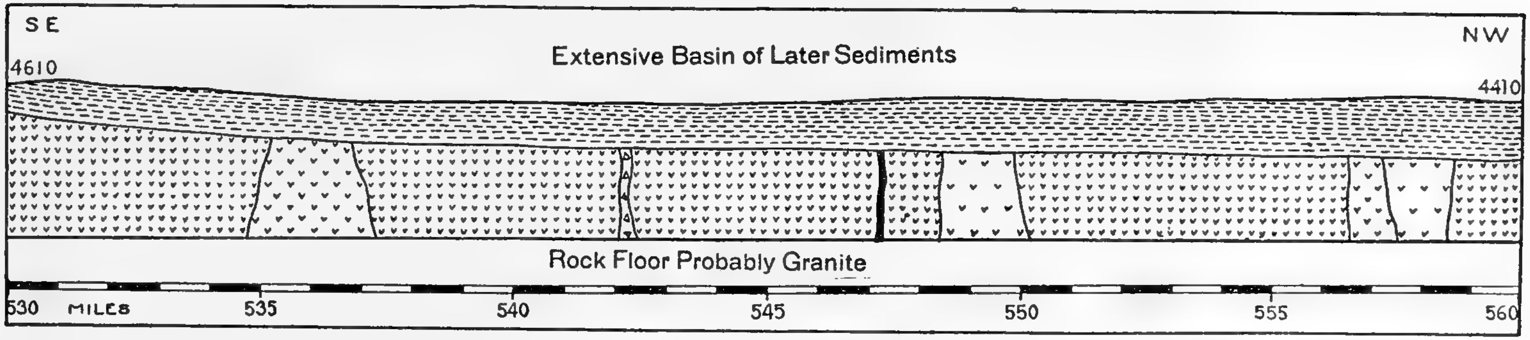


FIGURE 24.—A broad basin of later sediments, beveled by the Gobi planation surface. The country is remarkably smooth and level.

the year round we could not determine, but they appear to be permanent. Furthermore, they are not appreciably salt; at least, they are fresh enough to serve as a suitable water supply for herds. In every respect the country resembles the better portions of the great plains of the western United States, and gives one the impression that some of the land might well repay cultivation in the same manner. A country in which the native grasses grow so luxuriantly should mature crops of grain without irrigation. This northerly border of the Gobi region for 120 miles presents much the same character that one sees on the south border, where the encroaching Chinese colonists have already made good use of it. Doubtless there will come a time when this northerly border will be cultivated also; and when the limits of such encroachment are reached, the true desert region will be materially reduced, for almost a third of the Gobi country lying between Kalgan and Urga would encourage a much more intensive use than is now made of it.

The trail is smooth and forms a perfectly safe, first-rate road for motor travel over the whole of the sedimentary basin, from mile 524 to mile 577 (Figs. 23, 24, and 25). At miles 564–565, three small volcanic vents break through the sediments, which are well exposed on the flanks of the cones. The vents are apparently recent, and the openings are filled with scoria, pumice, pieces of breccia, bread-crust bombs, glassy crusts, and a great variety of vesicular material in excellent, fresh condition (Specimen 106, A.M. 9795). Some of the material is red and preserves fragments of sediments and traces of an original sedimentary structure, whereas other pieces seem to be as typically glassy and pumiceous lava as could be found anywhere. The adjacent sediments are not appreciably disturbed, and the whole relation seems to favor the conclusion that not only the red bricklike material, but perhaps the whole series of volcanic products at this spot is of purely local origin, made through fusion of the sediments by superheated volcanic gases. Although the cones are almost covered with fragments of this sort, they cannot have been built of the fragments, since unaltered sediments show on the flanks. This structure indicates, of course, that the cones are only in small part the result of accumulation, and are in chief part residuary after erosion—they stand above the general level because of their more successful resistance. No other igneous rocks were seen within the same basin, but five miles farther north a series of lava flows was encountered, lying on the sediments. They are vesicular trachytes succeeded by basalts and rhyolites (Specimens 107, 108, 109, A.M. 9796, 9797, 9798), and are apparently covered with sediments which give a very smooth surface for a few miles to the northerly limits of the basin.

The small volcanic vents seen at mile 565 are among the most striking expressions of volcanism seen in the Gobi region. It is not possible to date

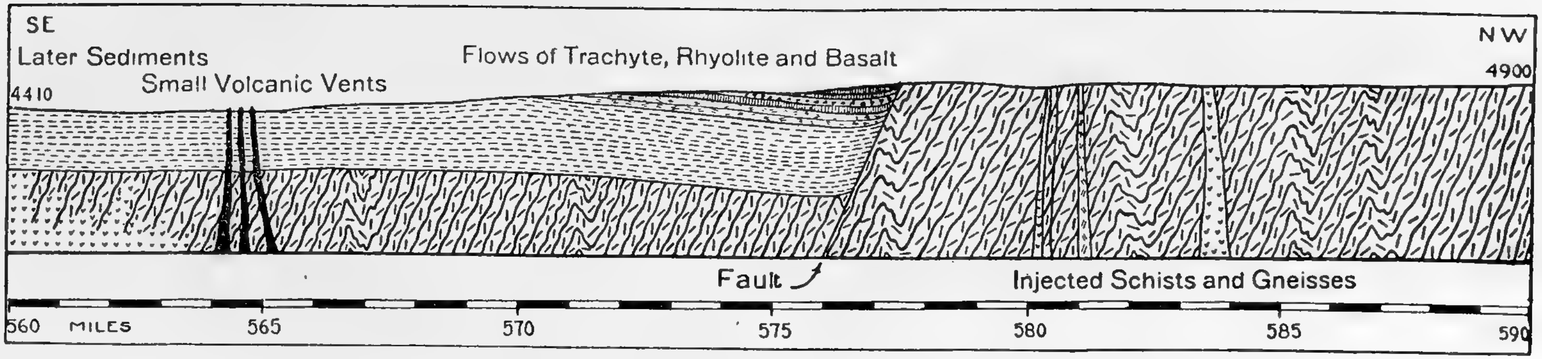


FIGURE 25.—The margin of the northernmost large sediment basin traversed by the Expedition, and the beginning of the upward slope into the Gangin Daba Mountains. The thickness of the lava flows between mile 570 and mile 577 is exaggerated.

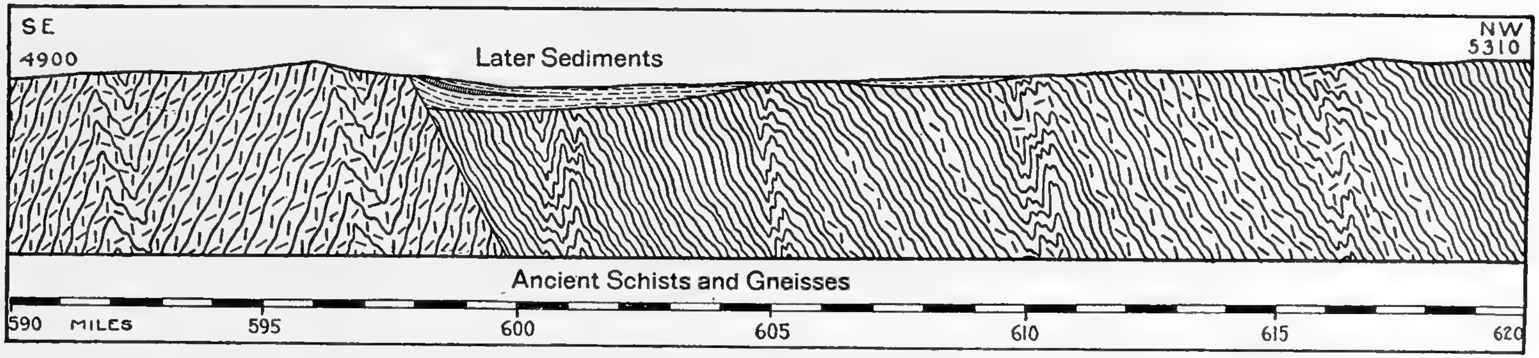


FIGURE 26.—Gradual rise on the southern flank of the Gangin Daba Mountains, which here form the northern lip of the great basin of Mongolia.

the outbreaks because the age of the sediments is not determined. One of the most surprising things about the small cones is the great range in quality of the material found on them. The maximum diameter of the top of the first of the hills is not more than fifty feet. The second one is larger, but apparently not over a hundred feet. There are no other representatives of volcanic activity until the flows five miles to the north are reached. Perhaps, however, the vents belong to the same epoch as the flows, and mark the escape of gases from the same under-sources which gave rise to the flows.

At mile 577.5, the sedimentary basin is abruptly terminated, probably by a fault, and ancient granite gneisses (Specimen 110, A.M. 9799) form the floor for ninety miles. They are cut by dikes of granite and trachyte porphyry (Specimens 111 and 112, A.M. 9800, 9801). The ground is for the most part thinly covered with soil, but outcrops are frequent enough to determine the quality of the floor. The composition of the rock is that of granite; the structure is strongly gneissic, thoroughly crystalline and considerably injected. The strike is across the course of the traverse; typical measurement gives strike N. 55° E., and dip 80° S. There is considerable variation, however, in both strike and dip. The rock is a true gneiss. It shows shearing effect and has the appearance of being the most thoroughly metamorphosed and perhaps the most ancient formation in the region. This type of country continues from mile 577.5 to mile 598, a distance of twenty miles (Fig. 26). In a general way the character corresponds closely to that of the T'ai Shan complex of China as described by Willis.

At mile 598, basin structure is encountered again, with basalt flows and sediments not very unlike those seen a few miles south, but on a much smaller scale. Outcrops are few and the structure is obscure, although the dip of the flows first encountered is to the north. The basin continues to mile 604, a distance of over six miles, where the old floor comes to the surface again, apparently by warping. The formation here, for several miles, is a blackish-green schist with a strongly developed structure, a strike N. 45° E., and a dip to the northwest at a steep angle (Specimen 116, A.M. 9805). This is undoubtedly one of the ancient series also, but its relation to the gneisses, on the south side of the basin, is undetermined.

The same formation continues for two miles, then is covered for several more. At mile 610, the granite gneisses with interbedded schists appear as the floor again, very similar in general quality to those seen twenty-five miles to the south. They are succeeded in a few miles by greenish and black schists, which continue to mile 622 (Fig. 27). The schists are spotted and streaked and very micaceous, and even, in places, very carbonaceous (Specimen 118, A.M. 9807). There are many whitish, lenticular bunches that look like pebbles which have been sheared out and turned into sericite and quartz.

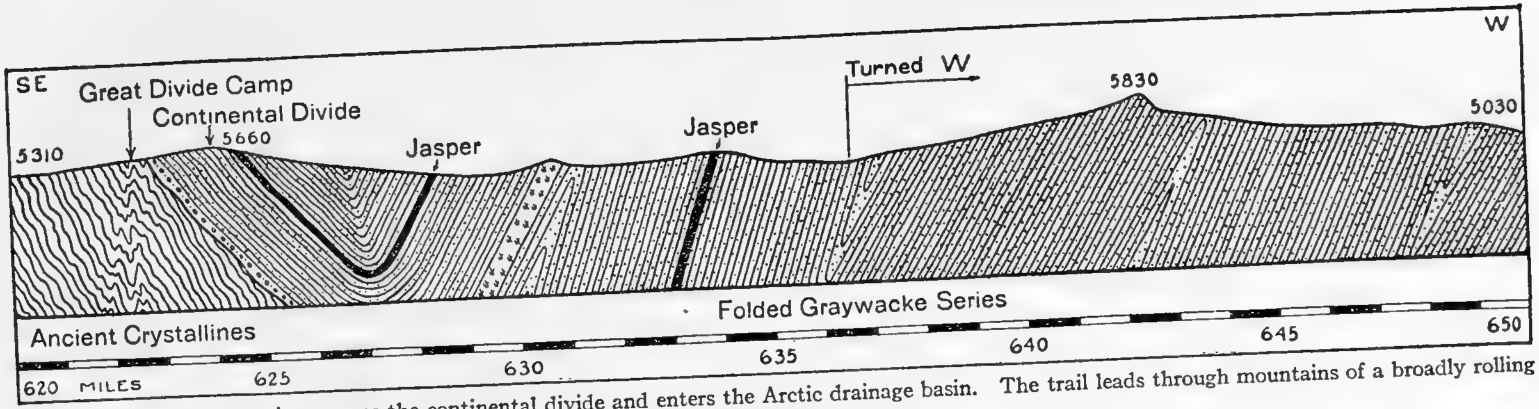


FIGURE 27.—The section crosses the continental divide and enters the Arctic drainage basin. The trail leads through mountains of a broadly rolling topography. Near the divide the schists give way to a large area of graywackes and slates.

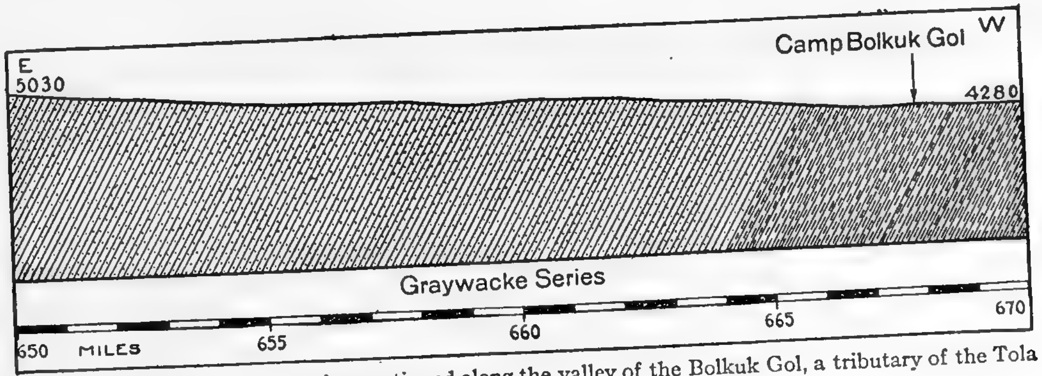


FIGURE 28.—Geologic section continued along the valley of the Bolkuk Gol, a tributary of the Tola River. (See figure 29.)

The range of composition indicates rather definitely a sedimentary origin. The formation is cut by numerous quartz veins, and occasionally by dikes or sills. The average strike is not far from east and west—N. 80° W. is a common measurement. In general this formation has a simpler appearance than the gneisses and is probably younger. The green schists probably belong to the Wu T'ai system of Bailey Willis (1907, II, page 4). This formation continues to the Arctic divide at mile 624.

The Arctic divide

An inconspicuous ridge marks the dividing line between the water sheds of the desert and those of the Arctic. From this point northward and westward for many miles the traverse lies within the Arctic slopes; and with this superficial change there is a complete change also in the geology. An entirely new series of rock formations constitutes the floor, and no later sediments are preserved. At mile 623 beds of graywacke and quartzite (Specimen 119, A.M. 9808) form the adjacent hills. The rocks have a very definite, bedded structure, dipping gently to the north, and are very hard and resistant to weathering. Associated with them are interbedded layers of jasper (Specimen 120, A.M. 9809) and quartzite, but the dominant type is a graywacke. Farther along, interbedded slates are abundant, but are inconspicuous in the portion of the formation represented in the first few miles. The beds first dip to the north, then in the course of a few miles the dip reverses toward the south, apparently repeating the formational succession. The hills are grass-covered, and the country becomes mountainous though not very rugged.

The structural relations between the graywacke formation and the green-black schists seen farther to the south are not determined, though it is entirely possible that they could readily be worked out in the vicinity of mile 622. In our rapid reconnaissance, however, we had time to note only that the quality of the floor and of the topography changes markedly in a comparatively short distance.

The graywacke series continues without interruption and without marked change of quality, except an occasional intrusion of igneous rock, to mile 636 along the main trail, and is known to continue on the same trail to Urga. At mile 636, however, the direction of the traverse was changed, and, led by a Mongol guide, the Expedition turned westward through valleys parallel to the main mountain range, the Gangin Daba. Then by side trails over the alluvial slopes of the ridges, the course continued thirty-two miles, to the Bolkuk Gol, a tributary of the Tola River (Fig. 28). This change of direction carried the party diagonally across folded graywackes and graywacke-slates to the new camp. Much of the journey lay over the trails of herds, and part of it over alluvial slopes without a single mark of travel, yet in the whole distance of thirty miles, after departing from the main caravan trail, not a single stretch of ground too difficult for the motors was encountered.

Small streams appear here and there in this territory, and large flocks and herds were seen everywhere. It is an ideal grazing district, but there is absolutely no cultivation of the soil. Alluvial slopes extend down from the higher ridges into the valley, but they are not heavily bowlder-strewn and are nowhere deeply dissected. Rock ledges are exposed extensively in the hills and locally along the valley floor on the banks of a stream.

Although mountainous country with more abundant precipitation has been reached, there is no evidence whatever of general glaciation. The soils

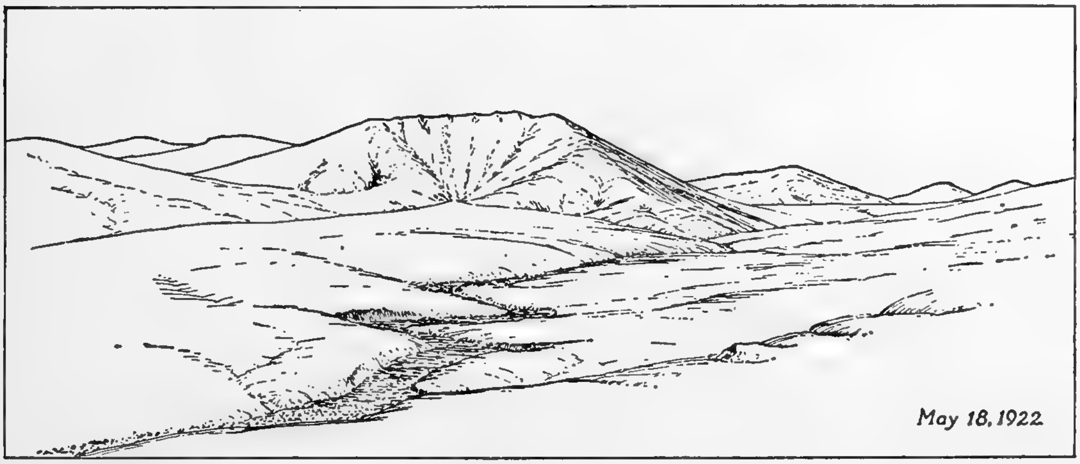


FIGURE 29.—The northern valley wall of the Bolkuk Gol. The bowl-shaped head of a small lateral valley resembles a cirque. It is possible that the shape of such valley heads is due to local glaciation. The floor is solid rock, and at least the upper part of the sloping approach to the bowl is over bare rock.

and deposits of all kinds are essentially alluvial. But some valley heads in the side of a mountain present the form of a cirque, and it is believed that these are evidences of former very small, local glaciers of alpine type (Fig. 29). At best they could have been of little consequence, although it is difficult to see how the forms could be developed without the action of ice. Only three or four such bowl-shaped valley heads were seen along the Bolkuk Gol, but several hundred miles farther west, in the Sain Noin country, much more typical cirques were seen and accepted, without question, as of glacial origin.

OBSERVATIONS IN THE VICINITY OF CAMP BOLKUK GOL

Bolkuk Gol, fifteen miles southwest of Urga, became the second rendezvous. Here, near a local shrine, the whole Expedition assembled for the first time, and established headquarters for the various parties, while Mr.

Andrews was completing negotiations in Urga for the further progress of the Expedition.

On the traverse across the Gobi we had become accustomed to a great variety of weather. The first day had ended in rain. It was generally cold, but while we were at Iren Dabasu, several days were uncomfortably hot. On the way to Mount Tuerin, snowstorms were encountered, and a short part of the traverse was made in the snow. As the party traveled northward the cold increased, and, with the high winds that prevailed, some of the work was done under extreme discomfort. On the whole, however, the air was dry, clear, and bracing.

The extreme cold of the season came at Camp Bolkuk Gol, where the temperature readings, through the four days at this camp, ranged from 50° Fahrenheit on May 15 to 17° on May 19. Readings just a little below freezing were more common. Such temperatures as this, with the high winds, made the task of keeping warm a difficult one for those of us who had work to do on notebooks or maps; nevertheless, the surrounding country was scouted persistently, since this camp was to be our closest approach to the city of Urga.

Although the Bolkuk Gol valley is well grassed and is largely alluvial, there are many outcrops on the higher reaches of the valley side, as well as along the course of the creek. Everywhere the rock is either graywacke, argillite, or quartzite. These different varieties belong to the same large, important formation, characterized by dominance of graywacke over large areas and by argillites in others, or by interbeddings of these two types. In many outcrops of the graywacke the rock is almost structureless; but wherever the argillites occur in them the bedding features are comparatively regular and strongly marked. In general the strike is N. 60° E., with variable dip, representing a succession of folds. In many places the dip is vertical or overturned. This general structural habit prevails over the whole territory crossed from the main Urga trail to Bolkuk Gol, and afterwards was found to continue for a very long distance to the west. Toward the north, also, as far as our explorations were carried, the same formations and formational habit prevail, extending through the Tola River valley and the Gangin Daba range.

Igneous rocks and igneous influences are insignificant in this whole territory adjacent to the Bolkuk Gol, although there is an occasional dike, and perhaps there are metamorphic effects that are too obscure to trace. Farther to the west, however, these igneous associations are greatly increased. The deformation represented by the graywacke-argillite series is that of mountain folding, of a regularity and persistence that is very striking indeed. The topography is markedly different from that seen farther to the south, where the country is characterized by the alternation of basin-filled sediments and almost peneplaned oldrock divides. Here, on the contrary, the country is mountainous, with subdued ridges and open valleys. The slopes are gentle, especially as they approach the valley bottoms, and become much steepened in the higher valley sides. All the slopes carry much finely broken material, weathered to soil so that it is practicable to drive with motors even without the aid of a trail. These slopes are remarkably free from gullies and outwash courses, although there are occasional small side streams across which one has to pick his way. Little material is being added or taken away.

Course of the Bolkuk Gol

In view of the fact that the rock structure of the region strikes N. 60° E. or thereabout, and is of approximately the same quality on both sides of the valley of the Bolkuk Gol, it is surprising to find the course of the stream so poorly adjusted to it. The course lies diagonally across the structure. It may follow a fault weakness, or it may, on the other hand, be a superimposed stream, preserving a course inherited from an original drainage that was developed on some overlying formation which has been completely removed. Later experience in other districts on the margin of the Gobi strengthens the inference that the superimposed stream explanation is probably the better one. It is not an uncommon thing to find stripped areas where former overlying sediments have been completely removed, and yet in such physiographic relation that this step in its history is perfectly clear. It is only a step, therefore, to such conditions as are presented at Bolkuk Gol, where mature dissection has been reached in the underlying floor subsequent to the stripping. The first stages, therefore, must have been reached much earlier in the history of the Gobi region, and perhaps the stripping, in this case, corresponds to one of the periods of marked erosion, such as that following the Cretaceous, or in one of the earlier epochs of the Tertiary.

The stream is a misfit in a valley too large for it, and there is a crude development of planation that should correspond to one of the planation epochs of larger development in the Gobi.

Glacial evidence in the Gangin Daba

The dominant erosion form is that of simple weathering and stream work, but in a few places the heads of tributary valleys present a form which attracts special attention because of its similarity to that of a cirque. No perfectly formed cirques were seen in this vicinity, although several were found in the Sain Noin region much farther to the west (Plate XIV, B, page 130). At Bolkuk Gol, however, there are the unusually steep heads of three or four side tributaries. They are crudely bowl-shaped, with a distinct change of grade below the first portion of the deepened course (Figs. 29 and 30). In one of them the excavation is made directly across the geological structure, on rocks so slightly different in quality that there seemed to be no good structural reason for the form, unless, indeed, it had been made by ice. The floor is virtually bare rock, and this, we believe, adds to the evidence favoring a glacial gouging action. The bowl-shaped valley heads have not the freshness of the cirques which were developed in the latest stage of the Ice Age. Their form is subdued by weathering and stream erosion, and if they are of glacial origin, they must have been made during one of the earlier glacial advances.

It is very clear that even in the mountains around Urga there is no evidence of extensive glaciation. In the entire region there are no glacial de-

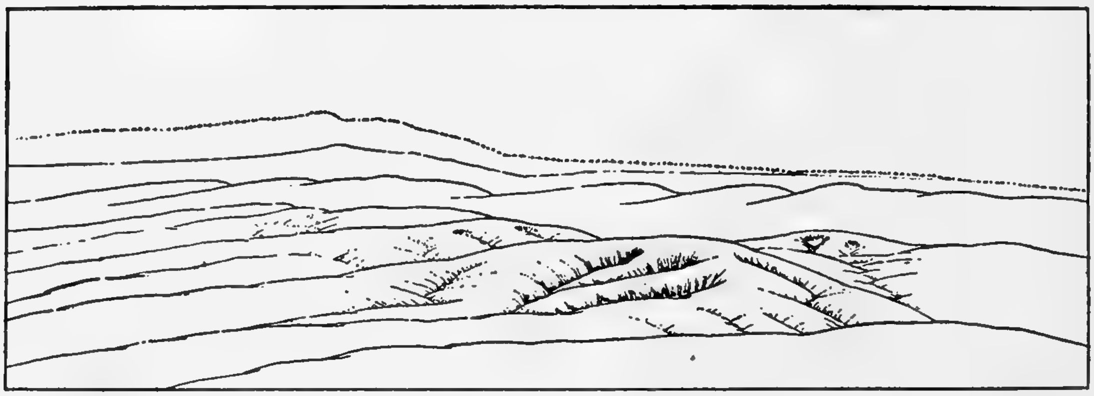


FIGURE 30.—Field sketch in the Gangin Daba Mountains near Camp Bolkuk Gol. The streams head in deep, bowl-shaped cavities which resemble cirques and may be due to a brief glaciation. (Compare with Plate XIV, B, page 130.)

posits and no suggestion of the presence of an ice-sheet. During the glacial period this may well have been a very cold, desolate region, but evidently there was so little precipitation that an ice cover could not form, and, at best, only here and there were small alpine glaciers developed.

This kind of history is indicated still more clearly in the district of Sain Noin, where there is an entire lack of evidence of general glaciation, but where glacial cirques are prominent, with characteristic form and product. Throughout the whole Pleistocene, therefore, it appears that this region was exposed to destructive attack from the ordinary surface agents. Erosion and deposition continued, in so far as they could continue with changed climatic conditions, in the whole Gobi area, while regions much farther west and favored with much heavier precipitation, were covered with glacial ice. No exception to this rule was found in all our traverse in the Gobi. Nowhere, even in the highest mountain ranges, was there evidence of glaciation, except the former existence of small alpine glaciers.

Ground ice

A curious instance of ice beneath the soil was found first in the vicinity of Camp Bolkuk Gol. In one portion of the valley bottom, attention was attracted to a system of nearly straight, knife-sharp cracks cutting the turf. The valley bottom was well grassed and constantly pastured by herds of cattle and sheep. On examining the exposed edge of this ground, along the trench made by the creek, we discovered that the turf was underlaid by a stratum of ice a few feet thick. The overlying soil attains a thickness of one to two feet. The chief interest lay in the question whether the ice is a comparatively permanent member of the soil system, or whether it is formed each year by some method of accumulation beneath the soil. The smoothness of the soil-surface would argue for comparative permanence. If as much ice as this were to form each year and be dissipated each summer, the repetition of lifting and dropping the soil layer with its many cracks should result in considerable deformation of surface. Some deformity was observed at the edges of the system and at places where thawing was more active, but on the whole there was little irregularity traceable to this cause. We are inclined to think, therefore, that the ice layer does not wholly thaw away in the short summer season, and that such thawing as does take place proceeds with enough regularity to prevent irregular slumping. Apparently the ground water, fed from the adjoining hills, enters the valley bottom and circulates in the gravel beneath the turf at about this level, and develops a layer of ice as freezing proceeds in the winter season. Coming as a sheet of water, rather than as a spring, it develops a thicker and thicker layer beneath the tough mat of turf.

A similar process was noted at Sain Noin, at a valley-side spring. In that case a mound several feet high, the core of which was solid ice, was formed by lifting the firm turf layer. At the time this particular formation was observed, the first warmth of spring had thawed the ice far enough to have destroyed the peak of the mound. The turf had been cracked far apart, and thawing had proceeded in the open portion, where a pool of water was held in by the surrounding ice and turf. Whether the ice accumulation at the spring is wholly destroyed each year and a new deposit subsequently developed with each winter season, we were not able to determine; but here again the simplicity of the form as a whole suggests the comparative permanence of it, as though the ice were not each year wholly destroyed. Probably the more fully covered portion is preserved beneath the soil.

Opportunity was not presented for other observations upon this undersoil ice, but in many places similar physical surroundings were duplicated. Underground ice seems to be a common feature in this far north country of small surface precipitation.

Local culture

Here, at Bolkuk Gol, for the first time, conditions were found favorable for the support of large numbers of people. The country, although mountainous or very hilly, is well grassed, even far up on the mountain sides. Flocks and herds can be kept in large numbers, and villages are comparatively numerous. Urga, the capital of Mongolia, lies in the district and is said to have 20,000 inhabitants. On one of the adjacent mountain ridges bordering the Tola River is located the lamasery, which is the seat of the Great Lama, formerly the actual ruler of the country and still the head of its whole religious system.

In spite of the fact that the camp stood within fifteen or twenty miles of the city of Urga, it was thought unwise to take the caravan or other equipment into the city, because of a feeling of uncertainty in government circles about the nature of the Expedition and the advisability of allowing it to continue upon its exploratory work. It was thought that further delay might be occasioned by any move of this kind. Mr. Andrews, therefore, and Mr. Shackelford, with Mr. Larsen, the official interpreter, conducted negotiations within the city and ultimately secured the desired permit to continue. As soon as this was done, the whole Expedition moved westward, on the traverse which led to Sain Noin and to the Altai mountains.

Side traverse towards Urga

During the stop at Bolkuk Gol, a side run was made toward the city of Urga, for the purpose of connecting the geological section with that point (Fig. 31). The same formations continue, with graywacke as the dominant type of rock. In the cross section representing the side traverse, for the first time a clear-cut, anticlinal fold in the graywacke series was detected. The fold lies within the valley of the Tola River, which apparently is developed in large part on such an anticlinal structure. The strata on the south side dip toward the south, and those on the north dip northward. Whether the anticline extends across the whole valley we could not tell, because we did not cross the valley, but the minor structure is clear-cut and simple, and the rocks on the south side of the valley correspond to the structure on a large scale.

The geologic section of this side traverse, added to the distance covered after leaving the Urga trail to Bolkuk Gol, shows nearly fifty miles on a single rock formation; but the course taken is roundabout and therefore gives an exaggerated picture of the importance of the simply folded graywacke series. If the traverse had been continued directly to Urga from mile 636, it could have been completed in an additional twenty miles, and the structure would have been correspondingly simpler. It is evident, however, that the same type of country prevails still farther to the north, and later experience showed that the series of formations encountered here, forming the basis of these mountain ranges, characterizes the country and gives it its mountainous aspect for several hundred miles to the west. It is evident, from the immense area covered and the many miles that one may travel across the truncated

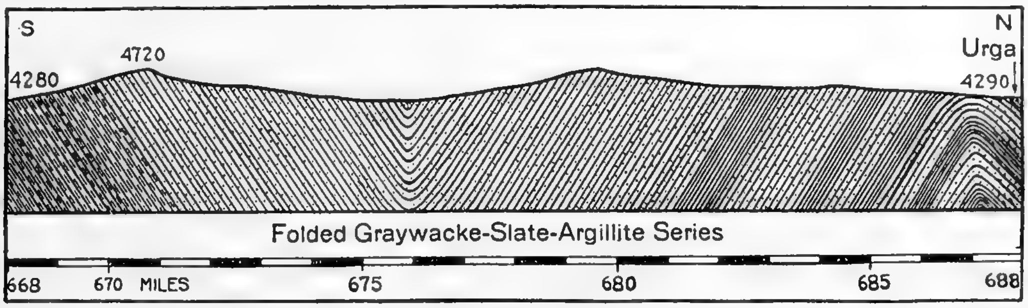


FIGURE 31.—Side traverse from Camp Bolkuk Gol to Urga through open folds of graywacke, argillite, and slate.

edges of the strata, that this is one of the great formations of Mongolia. Its enormous extent, its constancy, and the complete failure of fossil content, make it not only an important structural element but a great geological problem as well.

Mineral resources

It is well known, of course, that there are mineral deposits within the borders of Mongolia, not far from Urga, but the conditions where these occur must be materially different from those prevailing in the districts farther south. There are probably few regions in the world with a mineral supply as scanty as that of the greater portion of the Gobi desert. Mineral development is a practical impossibility. It is appreciated, of course, that this comment does not apply to the marginal country where the geologic conditions may be very different, but it does apply to the region as far north as the Tola River, in the vicinity of Urga. In this traverse of more than 650 miles, not a single mineral specimen of economic interest was discovered. Quartz veins were seen by the thousand, and rock ledges of all kinds were examined, but no promise of economic returns was found in them. A few beds of coal of poor quality were seen later in Jurassic strata farther to the west, and coal may possibly exist in the Jurassic formations crossed by the traverse to Urga, but it was not exposed, and none, thus far seen anywhere in the Gobi, is of sufficiently high quality to attract attention. Besides these coal beds there is nothing of economic interest, and at present they have absolutely no value. We believe that there are good reasons for the mineral habit here encountered, and for the fact that in some of the marginal country much better conditions are reported. This will be discussed more fully, however, at a later time, in connection with the final summaries, which, it is hoped, may grow out of this series of studies.

CHAPTER V

FROM URGA TO TSETSENWAN

On May 19, in an early morning temperature of 17° Fahrenheit, we began the westerly traverse from Camp Bolkuk Gol. Our way lay through valleys tributary to the Tola River, and within ten miles led into the main caravan trail along the Tola River from Urga to Sain Noin (Fig. 32). The route at first followed an exceedingly roundabout course, and was covered more deeply than usual with soil and river alluvium, presenting great difficulties in the task of keeping a true geologic cross section. We have, however, attempted to do this, by eliminating as much as possible of the duplication, and by reducing the whole traverse to simple structural form.

TRAVERSE ALONG THE TOLA RIVER

When the course has reached the Tola River it becomes more direct, and continues so for many miles, though outcrops are less frequent. The average course cuts diagonally across the general formational trend, at a low angle. There is nowhere any doubt about the character of the underlying formation. It is the graywacke-argillite series, with simple folded structure and post-mature erosion. The recorded dips indicate that the first day's journey crossed two large folds in this diagonal manner.

At numerous places the terraced form of the valley appeared prominently. The Tola is one of the great rivers of northern Mongolia, with a course westerly and southwesterly from Urga for about fifty miles, before it makes an abrupt turn to the north, joining the Orkhon River and following the Selenga drainage to Lake Baikal. For the greater part of its course the Tola seems quite independent of the folded structure of the country, although in minor respects some adjustment is evident. The valley ranges from three to five miles in width, and has a wide, flat floor on which the river meanders broadly. The flood plain is bordered by wide rock-terraces bearing remnants of older alluvium.

For fifty miles our route lay along the Tola River, so far down in the valley that the traverse profile is unusually monotonous and the geologic structure largely a matter of inference (Figs. 32 and 33). Outcrops are rare along the trail, and it was thought inadvisable to take the time to check by means of side excursions, since there was no doubt whatever of the general structural relations. But as the traverse proceeded, igneous activity became more and more evident. An occasional dike of porphyry appeared at first, and as we progressed these occurrences became more numerous and more prominent. At the Tola River camp, mile 732, sixty-four miles southwest of Bolkuk Gol, we saw in the distance many of these large dikes in the mountain-sides across the river (Fig. 34). They can be traced in parallel alignment, brought out by differences of relief, since most of them are more resistant to weathering than the graywackes and slates through which they cut. They constitute a striking minor physiographic effect. Evidently they are the result of outbreak from some extensive magmatic body which lay beneath. Further explorations along this traverse were soon to reveal the character of this igneous mass, but up to this point its nature had not been determined.

At mile 748, the trail turned southward, leaving the valley of the Tola River, and began to climb into higher country, at the same time turning more directly across the rock structure of the region. The same kinds of graywackes and slates continued for another day's journey, but igneous intrusions increased in number and size. The commonest rock type is a form of granite or granite porphyry, and an occasional mass of this kind stands in isolated mountain-like relief, adding materially to the picturesqueness of the country. It is clear that the igneous rock has forced its way up through the graywacke-slate series and is a much later formation, yet there is, in most cases, very little metamorphic effect. This is especially true where the granites break through almost vertically.

In a few places, however, where there is reason to believe that the contact is more gently sloping, we noted a variety of metamorphic effects. In some places the formation becomes phyllitic and schistose, and much more crystalline than the original rock. These changes are so striking in the vicinity of the first camp south of the Tola River, located at mile 769 and called Five Antelope Camp, that specimens of the modified rocks, taken out of their known setting, would present few evidences of their true relationship (Fig. 35). One would be inclined to classify them with older and more uniformly metamorphosed formations; but the party was fortunate enough to find all gradations of quality in the neighborhood of the camp, from the simple graywacke-slate varieties to highly metamorphic phyllites and schists,—the difference appearing to depend on their proximity to or distance from the igneous contact.

In this locality, granite and granite-porphyry outbreaks constitute at least a quarter of the total section, and as a consequence a much greater pro-

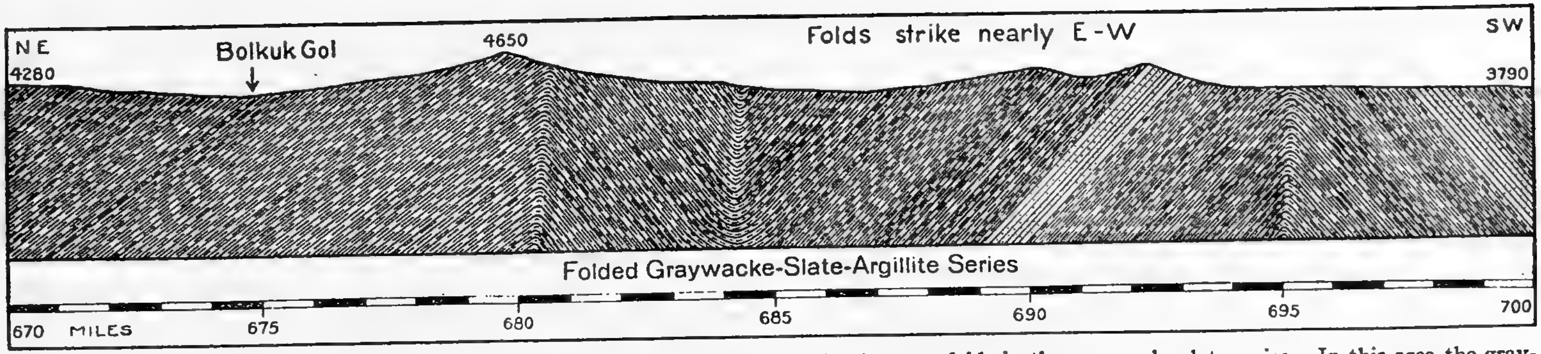


FIGURE 32.—Geologic section from Camp Bolkuk Gol to the Tola River. Simple, open folds in the graywacke-slate series. In this area the graywackes predominate, and igneous rocks are almost wholly lacking. Because there are no readily identified "key beds," or definite horizons, the entire section is necessarily generalized.

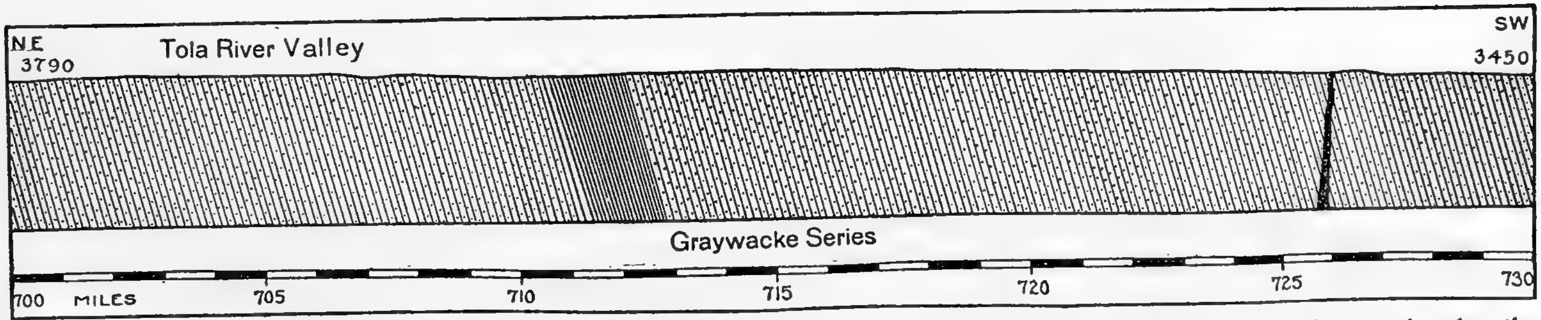


FIGURE 33.—Geologic section in the Tola River valley. The section is taken along the river valley and therefore appears far smoother than the surrounding mountainous country. Much of the rock floor is covered. This fact, together with continued lack of "key beds," has made it impossible to determine the position of folds, and the section, therefore, has been generalized to emphasize the prevailing southerly dip and the monotonous sequence of graywackes.

portion of the associated rocks are modified, and attain greater complexity of composition and minor structure than elsewhere. These intrusives are all doubtless representatives of an underlying magmatic body,—a mass that we later designated as the great Mongolian bathylith (Berkey and Morris, 1924*a*).

THE VICINITY OF FIVE ANTELOPE CAMP

A day's stop at this camp enabled us to make a more thorough inspection of the rock floor, which had attracted attention at the close of the preceding day, and which proved to be more complex than any within the last hundred and fifty miles. There is considerable schistosity, with a great abundance and variety of igneous material. Not only is the igneous content abundant, but it has its own complexities, represented in great numbers of dikes and sills, stringers and lenses of almost every range of composition between alaskite and pegmatitic quartz on the one hand, to the composition of a dolerite on the other.

The foundation rock is a sediment, very siliceous and of rather obscure structure. It is highly indurated and tends to become phyllitic. The general strike is nearly east and west,—N. 80° E. being one of the definite readings,—and the intrusions take on about the same structural trend; some of them show streaked structure, in contrast to the majority which do not show any similar deformation effect. They cut each other in a complex way, and some of them include xenoliths exhibiting a schistose structure older than the intrusion. Such phenomena seemed to indicate beyond question that the formation was considerably metamorphosed before these igneous members were injected into it, but it still was not clear whether this particular igneous activity was responsible for the greater metamorphism of the formation found at this camp.

The first working hypothesis assumed that there are two very different formations,—one the graywacke-slate series of the country traversed from Urga to this camp, and the other represented by this more metamorphic type of rock. Such field examination as could be made, however, failed to show any distinct break in the sedimentary series, and it was finally concluded that the whole assemblage of beds, with its many differences of condition and quality, really belongs to the graywacke-slate series, and that the strip of ground between the granite gateway at mile 760 and Five Antelope Camp at mile 769 represents a deeply eroded anticline in this formation. The center of the anticlinal arch exposed the lower beds of the series, which are somewhat different from the upper members over which most of the traverse had been made. They have also been modified extensively by the encroachment of a bathylithic granite mass, which in some places sent into the former roof larger intrusive masses which now stand as granite mountains at numerous points in the vicinity. Some of these are essentially stocks or bosses, many of which stand in very bold relief above the average sweep of the country.

The sedimentary formation, interpreted in this way, includes not only the graywackes and slates or argillites but also a few beds of jasper and quartzite, as well as local developments of phyllite and of schist. Some of them are very massive and exercise a distinct local control in the deformation of the region, causing considerable minor crumpling and drag effect in the associated, less competent members.

The conclusion that no new formation had been encountered but that the difference in appearance and quality of the rocks is a contact effect, due to the influence of an underlying bathylith, served as a successful working hypothesis for the next steps of the traverse, and the experience of the remainder of the season's investigation tended to support this explanation in all respects.

From the field observations thus far made, it is reasonable to conclude that the great graywacke-slate series in this northerly region along the Tola River is made up of three members: (1) banded slates or argillites, which probably form the top; (2) interbedded graywackes and argillites, forming the middle; (3) quartzites, jaspers, and phyllites, forming the bottom. It is chiefly with the lower member of the series that we have concerned ourselves in the vicinity of Five Antelope Camp.

It is evident, of course, that the series must be of immense thickness—many thousands of feet—but there has been no way of determining its measure. That it is one of the great formations of the region is perfectly clear, and its general structural position is also determinable; but its exact age is in doubt, as no fossils whatever were recovered from it.

The origin of so immense a series of sediments, especially with the dominance of the graywacke type of sandstone and wholly barren slates, is equally obscure, and when one takes into account the great areal extent over which rocks of this type are now known to be distributed, one is confronted with a major problem of the geologic column, deserving special study on its own account.

FROM THE TOLA RIVER TO TSETSENWAN

After leaving the Tola River, the course of the traverse lay to the south and southwest across a region of broad, rolling topography, above the general level of which stand numerous rugged mountain masses of no very large extent (Fig. 35). These all prove to be igneous intrusions of granite-porphyry, granite or syenite. Their sharply defined, cliff-like margins rise abruptly above the general erosion level, which seems to control the rest of the topog-

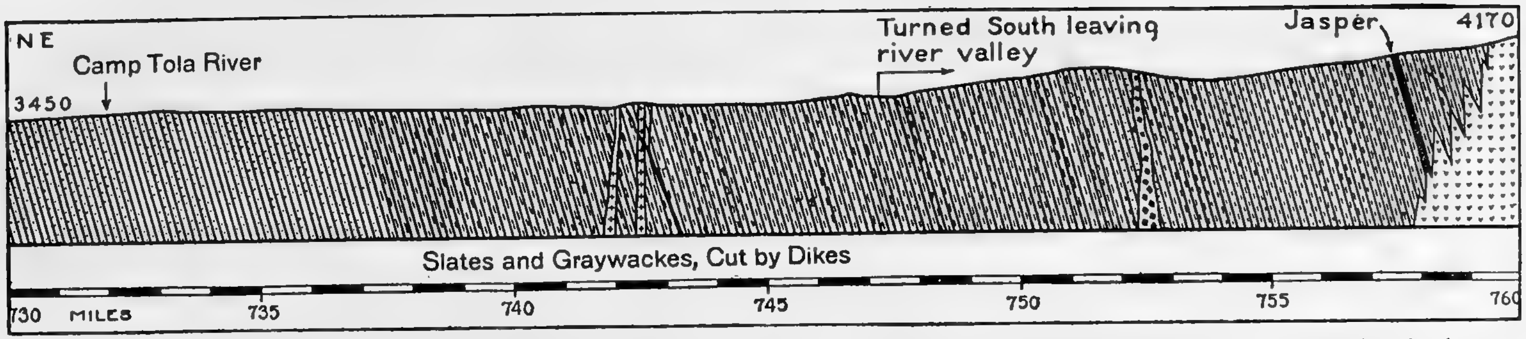


FIGURE 34.—Geologic section at Tola River Camp. Continuation of the simply folded graywackes of figures 32 and 33, generalized in the same manner. Toward the south, igneous intrusives increase in number and size until, at mile 759, the margin of the invading granite bathylith is reached.

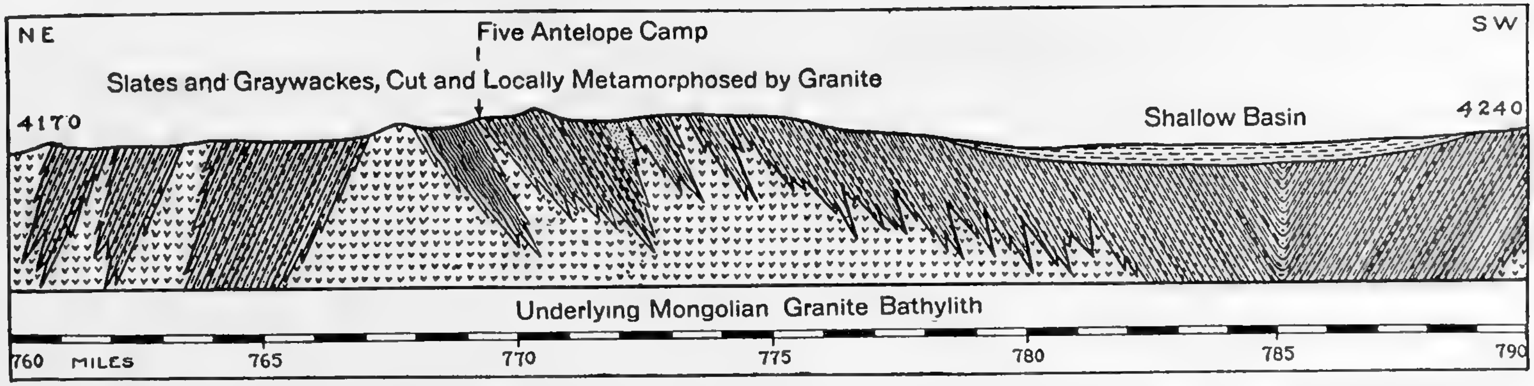


FIGURE 35.—Geologic section along the Urga-Tsetsenwan trail, across rugged country marked by many outcrops of granite protruding through the roof of graywackes, which still continue as the country rock, but locally are metamorphosed to schists and phyllites.

raphy. This habit prevails as far as one can see in every direction, and seems to characterize a certain zone of transition between areas in which the granite bathylith forms large portions of the surface, and others in which the overlying formations prevail.

One of these granite mountains, standing now as an erosion remnant, lies along the line of traverse a short distance southwest of Five Antelope Camp. In its vicinity all of the sedimentary formations are much modified, a condition which is due to the proximity of igneous masses. In the graywacke-slate series along this traverse, near the granite mountain, we encountered an extensive development of comparatively pure quartzite. It is, however, only a facies of the graywacke formation.

Our course led us to the southwest toward Tsetsenwan, past a lake basin from mile 780 to mile 790, small and shallow like hundreds of others scattered along the northerly border of the Gobi proper. It contains two small lakes, both salt; in one of which water was standing, while the other was almost dry. Accumulation of sediment is continuing in this basin, and on the margin at one or two points we saw a little of the exposed material; but it was not possible to determine either how much of an accumulation there was at this point or what its age might be.

Beyond this basin the graywacke-slate series continues with granite intrusions and many porphyry dikes, repeating the general structural relations of the country (Fig. 37). A considerable change, however, takes place at miles 795–796, where much greater igneous activity is in evidence. There are large black sills at mile 795, cutting through the graywacke, and at mile 796 a great exhibit of basalt and andesite flows and breccias. This is a type of rock entirely different from any seen within 200 miles, and it is clearly of much later origin than anything encountered since leaving the vicinity of Urga. Subsequent inspection revealed that there is a large crush zone, 300 feet wide, with no appreciable change of topography; the general erosion plane is unbroken. Here is evidently a great zone of weakness belonging to a large fault movement, and it is reasonable to assume that the lavas have found their way up along the weaknesses of the old fault zone. Structural relations such as this have been noted in many other places, particularly along the edges of faulted Jurassic strata; but this is the first time in the traverses of the Expedition that basalts and tuffs were noted wholly associated with very ancient formations. In all essential respects the products look the same as those associated with Jurassic strata. It is possible, however, that they are still younger, because similar outbreaks were noted in other places associated with fault blocks of Cretaceous and Tertiary age.

The igneous formations extend toward the south beyond the range of our inspection. Doubtless in that direction a more complete structural relation could be worked out. A traverse made from Tsetsenwan some days later, extending forty miles to the south, actually encountered rocks of this type associated with deformed Jurassic strata, and perhaps still younger formations. The two areas of igneous rocks are probably continuous, belong to the same structural unit, and have the same explanation.

The exposure at mile 796 is a remarkable breccia, almost like a conglomerate in form, three or four hundred feet wide in the best exposure, and varying in quality in successive layers or zones. In spite of this appearance, a thorough inspection indicates that it is essentially a fault breccia and belongs, undoubtedly, to the crush-zone already described. It is very deceptive because of its variable appearance, which strikingly resembles bedding.

Beyond the complexities introduced by the fault zone and the volcanics at mile 796, the traverse lay for a short distance across the graywacke series, and then over granite cut by many dikes, to the edge of a block of ground standing somewhat above the average level and presenting a rather abrupt escarpment ten to thirty feet in height, which proved to be the edge of another area of graywacke and slate. Further examination showed that it is again bordered by granite on the opposite side, two or three miles farther west. Moreover, when the northerly end of the block was reached by a detour on the trail in that direction, we found that there, too, it is bordered by granite. The block is clearly a great roof-pendant, wholly surrounded and supported by granite. It is not necessarily the first one encountered, but it is the first large, clearly outlined block whose structural relations we had been able to prove definitely. It is a typical roof-pendant, a remnant of downward extending portions of the original cap now almost completely removed by erosion.

Granite, cut by thousands of dikes, continues as far as the temple of Tsetsenwan, which stands on an alluvial fan at the foot of a mountain block. A run of several miles across the fan, to the mouth of a gulch at the edge of the block, brought us to the camp at Tsetsenwan, mile 815 (Fig. 36, A and B).

THE VICINITY OF TSETSENWAN

At Tsetsenwan a stop of several days was made, connection with the caravan was established, and supplies were obtained for the next lap of the journey, which would take us to Sain Noin. This stop afforded an opportunity for examination of the features of special interest in the vicinity, and for side traverses both to the north and to the south.

The district about Tsetsenwan proved to be especially favorable for the geologists. The key to several puzzling geologic problems was found at this place; in fact, some of the most fundamental structural relations, which have a bearing upon the geologic problems of the entire Gobi region, were exhibited

FIGURE 36A.—The fault block at Tsetsenwan. The front is abrupt, and a gently arched peneplane bevels the upland surface of the block.

so plainly here that they could not be mistaken. Among these problems are the following:

1. The bathylithic nature of the granites of Mongolia.
2. The contact metamorphic origin of many of the variations exhibited by the graywacke-slate series.
3. The extremely great erosion interval between the Jurassic strata and the graywacke-slate-granite floor.
4. The great thickness of Jurassic strata, and their simple folded structure.
5. The appearance of intrusive porphyries and outbreaking volcanics on a large scale, either during or immediately following the Jurassic period.
6. The probable unity of the varied igneous formations of the Gobi region, and their genetic connection with the great bathylith.
7. Block-faulting as a type of deformation in later geologic time.

A side traverse north of Tsetsenwan

North of Tsetsenwan a stretch of several miles is thinly covered with disintegration débris and soil, so that the character of the rock floor is a little more obscure than usual. The outcrops indicate that the chief underlying rock is a coarse-grained granite, which is cut by thousands of dikes of great petrographic variety and of equally variable size (Fig. 38). The dikes cut one another at all angles, and traverse the granite in winding, snaky courses, giving the landscape the aspect of some ruined city of giants, where the dikes are the wreck of a thousand crooked walls. Our field name for the district was the "country of the serpent-form dikes" (Fig. 39).

The serpent-form dikes

The dikes have a decided tendency to stand out in relief on the surface,—enough relief, at least, to make the courses of the larger ones readily traceable

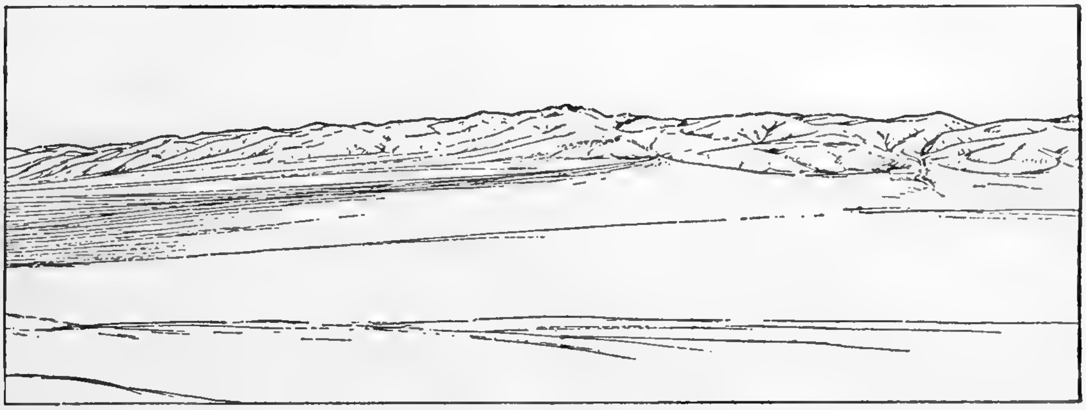


FIGURE 36B.—Continuation of figure 36A, the fault block at Tsetsenwan.

as one views such an area,—whereas the granite foundation through which they cut has been more deeply etched under weathering influences. This was noted repeatedly in areas of similar structural relation, where the granite surface, as now exposed, corresponds closely to the upper portion of the bathylithic mass, and where the roof has been removed.

Some of the larger dikes, particularly those of granite or granite-porphyry composition, take a comparatively direct course, as if following weaknesses of larger regional significance (Fig. 39); but the others are surprisingly irregular, and must have broken through the granite along weaknesses distinctly different in origin from those connected with regional deformation. Later observations of similar occurrences in other places,—none of them, however, as well developed as those at Tsetsenwan,—finally led us to the conclusion that, in spite of the great compositional variety, which ranges from alaskite porphyry to melaphyre, and in which undoubtedly hundreds of facies of a general porphyry type can be observed, the dikes are all the product of the differentiating granite mass itself. There is, of course, no way of proving this; but it is unbelievable that there are as many new igneous encroachments from beneath as there are types of rock. It is much more reasonable to suppose that the great bathylithic magma underwent elaborate differentiation over an immensely long period after its upper and marginal portion had cooled sufficiently to form the granite now found on the margins and beneath the old roof. Eruptive activity must have been many times renewed, and there must have been abundant opportunity subsequently for the sending out of molten material from the still unsolidified deeper portions. As the outer margins cooled still more and developed shrinkage cracks, and as deformation developed and originated other weaknesses, the still molten portions beneath were enabled to penetrate through the cap of solidified granite and into the roof. Under such conditions, multitudes of intruding tongues and stringers would develop, and an abundance of penetrating solution-differentiates would finally solidify in this marginal and roof portion, where they now appear as dikes.

If this were to happen repeatedly through long periods of time, at successive stages of local differentiation as diverse compositional concentrations were reached, there should be dikes of exceedingly great variety, as great in range of composition, indeed, as it is possible for the differentiation of a great bathylithic magma to produce in the whole course of its history. It is reasonable to expect that at certain stages the composition would not vary greatly from that of the granite of the roof itself, though the texture might be quite different. At the other extreme, it is reasonable to expect that very basic constituents should prevail and that a composition approximating that of a diorite, a dolerite or a basalt-porphyry should be produced.

With this explanation, the whole system of confused dikes takes on a comparatively simple genetic meaning. Even the great variety of composition is understandable, for it reduces to a single process. The dikes are all relatives—they are all the products of the same process—and they all come from the same general source; but they are of different ages, and represent very diverse stages and degrees of modification in the history of the original magma. It is our belief that they have no other significance, and that this interpretation is supported by the fact that the dikes clearly cut one another in a most complex, interlocking system, and present distinct proof, in themselves, that some of them had been formed and were solid crystalline bodies long before others were intruded.

If this explanation be true, the dikes present a most remarkable exhibition of the great range of differentiation products formed by a large bathylith. How many of them ever extended up into the overlying roof of graywacke-slate, one cannot tell; but the roof-pendants which still remain carry great numbers of them. This condition is admirably illustrated in the large roof-pendant east of Tsetsenwan which has already been mentioned in the itinerary description. The intrusives habitually take on a certain regularity imposed by the structural control of the bedded host. It is our observation that they are not by any means as numerous in the roof formation as in the granite beneath; and probably many of the dikes, especially the smaller ones, were virtually confined to the granite itself, penetrating its shrinkage cracks but not reaching far into its cover. At any rate, in immediately adjacent ground, where conditions should have been almost precisely similar, as, for example, in the ground north and east of Tsetsenwan, there is a much greater number of noticeable dikes in the exposed granite areas than in the ground still covered with the graywacke and slate.

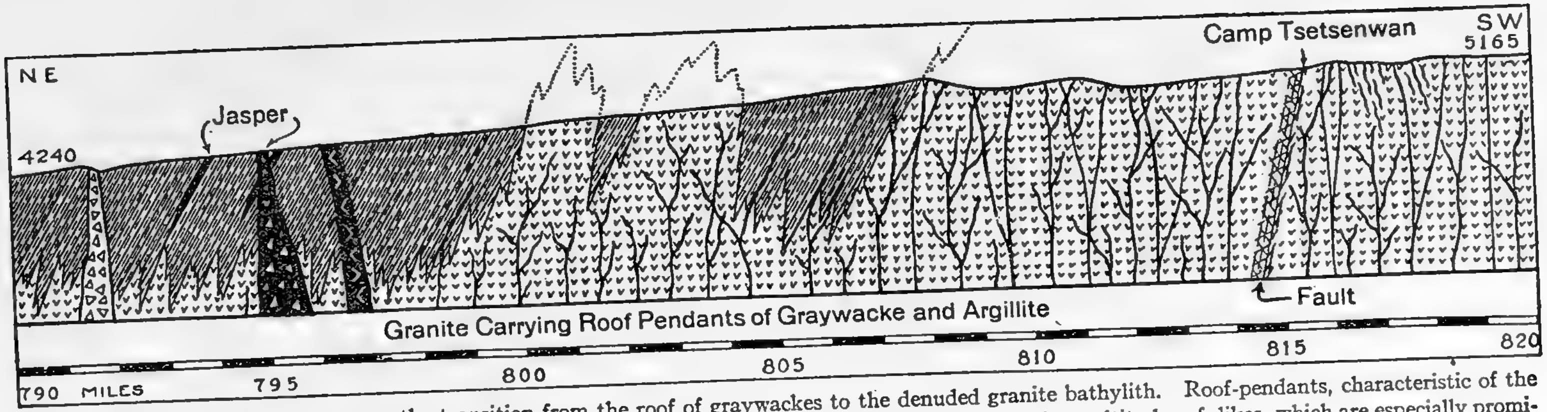


FIGURE 37.—The section covers the transition from the roof of graywackes to the denuded granite bathylith. Roof-pendants, characteristic of the upper zone of a great bathylith, are typically preserved in this locality. The bare granite areas are cut by multitudes of dikes, which are especially prominent in the Tsetsenwan district.

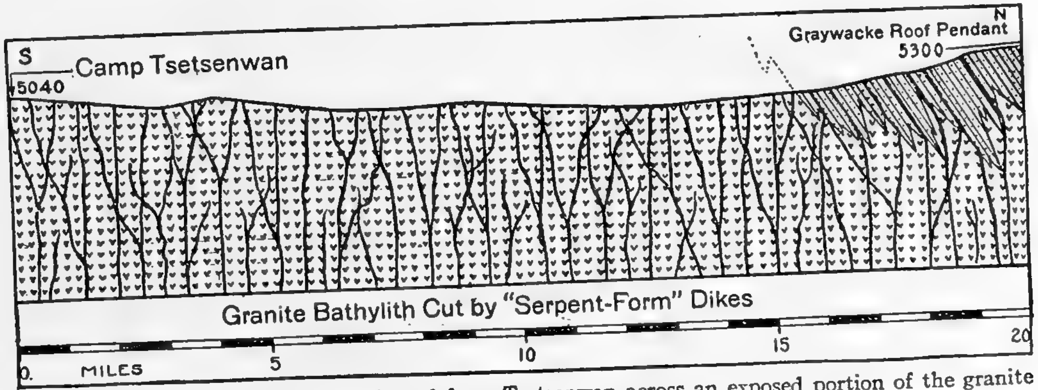


FIGURE 38.—Side traverse northward from Tsetsenwan across an exposed portion of the granite bathylith with its "serpent-form" dikes to the margin of the graywacke roof. The graywackes resist erosion better than the granite and therefore have greater relief. (Compare figure 39.)

Contact effects of the granite margin

The granite country, cut by dikes, continues for some few miles, beyond which the floor is again the steeply upturned graywacke series. From the first high prominence one can look out to the north and northwest over an endless sea of similar hills that are probably of the same formation. Turning to the north, a distinct line of demarcation was detected, dividing this rugged graywacke country from an area of more rolling ground. The latter is characterized by granite cut by the serpent-form dikes (Fig. 39). On the west side of the line the country exhibits a rugged character, with a mountainous aspect in the distance. It also has a certain regularity in the relief forms produced, because of the structural trend of the graywacke formation. At first we as-

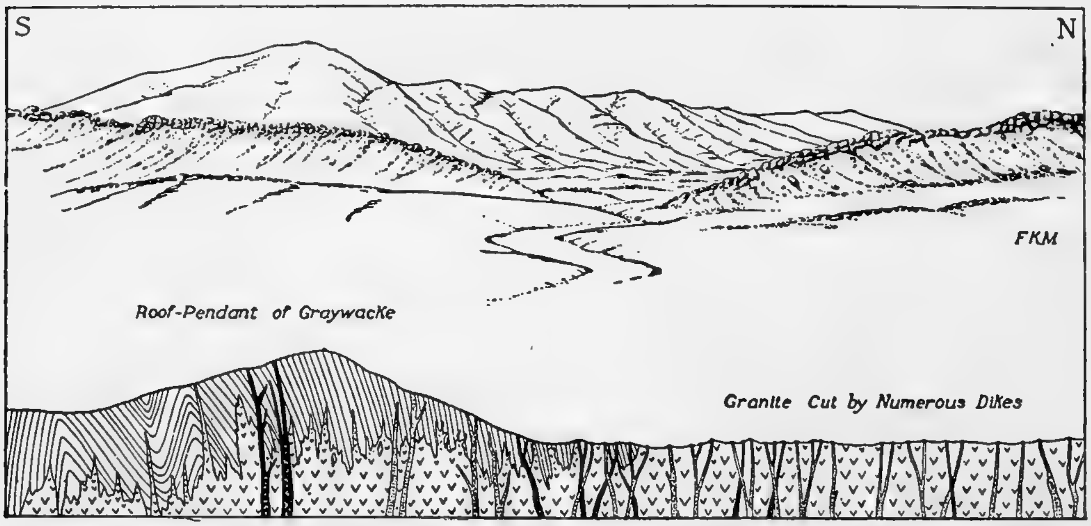


FIGURE 39.—Margin of a roof-pendant north of Tsetsenwan. (See figure 38.) The hills are of folded graywacke. The granite, less resistant than the graywacke, has weathered out to form a lowland, shown in the right-hand half of the sketch. The dikes withstand weathering better than the granite, and are etched out in relief so that they stand up like stone walls. The section below is drawn through the large obo-crowned hill in the background of the sketch, and shows the folded graywacke undercut by the granite, which is traversed in turn by a host of dikes of many kinds.

sumed that there must be a fault line between these two distinctly different types of country, and that considerable displacement might be represented in bringing side by side two areas so strikingly unlike.

A traverse was therefore made across this contact line, for the purpose of determining its structural significance. We had already noted that the graywacke-slate series in this mountain is exceedingly variable, showing considerably greater tendency to crystalline condition than usual, and that there are occasional small dikes or sills injected into the strata. When passing down over the mountain side to the contact zone at the base of the hill, we observed that the graywacke becomes still more complexly modified, and in places is saturated with and almost replaced by substances of foreign origin. One of these substances, most prominent in the changed material, proved to be tourmaline. This is, therefore, an igneous contact, and has no necessary relation to faulting. On crossing from the graywacke to the granite there is no deformation effect or displacement to be seen. The granite simply emerges from beneath the graywacke, which is extremely modified at the margin, the intensity of the modification diminishing noticeably with distance from the contact.

This exhibit proved beyond question that the variety of qualities in the graywacke seen at many other places, where question of its meaning was raised, is an entirely normal product of the contact with the granite bathylith. Close inspection was made of this ground, which is heavily mineralized, to determine whether it carries metallic content. Practically nothing of this sort was seen, even though extensive replacement and large introduction of other substances are evident. The mineralization is essentially of non-metallic type. Marked effects are produced, but metals are lacking. This may not be universal with respect to the Mongolian bathylith. It may be characteristic only of the central portion, while quite other conditions and products may characterize the marginal zone of the great mass. It is our judgment, from the structural relations encountered, that we did not reach such a margin on any other part of the summer's traverse; but we are quite prepared to believe that an entirely different mineralization might be found outside of the region covered by our own work.

Jurassic structural relations

The northerly traverse from Tsetsenwan had been undertaken in response to a report from local Mongols that "dragon bones" were to be found in that vicinity. We found none, and it is not at all likely that the strata of the locality could by any possibility furnish such material. The trip proved interesting, nevertheless, for our attention was arrested by two hills which are distinctly different in appearance from their neighbors, and which show an outline suggesting a much simpler structure than that of the granite or of the graywacke series (Fig. 38, and Fig. 126, page 293).

In order to examine these two hills, a second trip was made, which yielded very suggestive results. The formations involved in the two hills proved to be simple, unmetamorphosed sedimentary strata lying nearly flat, or at most, only slightly folded. The rock is conglomeratic sandstone, with plain bedding. It is almost devoid of fossils, but we discovered a few plant remains. Some of the stems of these plants are several inches across. They not only make impressions on the sandstone, but occasionally leave cavities in it, where the woody tissue has been removed by percolating waters. The fossils are not perfect enough to enable one to make specific determination of the age of the sandstone, but the fact that only plant remains are found in it led us to conclude tentatively that the formation is of essentially the same age as the coal-bearing sandstones of northern China, which have been assigned to the Jurassic. North of Tsetsenwan these strata rest unconformably on the eroded granite and its many dikes, whereas the graywacke series is invaded by the same granite (Fig. 126, page 293). It is clear that the graywacke series was folded and extensively invaded by granite coming from the development of a great bathylith beneath several hundred thousand square miles of territory. Then followed a long interval of erosion, during which the graywacke roof was worn away before the Jurassic conglomerates were laid down. Since the graywacke is invaded by the granite, while the conglomerates rest unconformably on the eroded surface of the granite, it follows that there must be a great difference in age between the graywackes and the conglomerates.

The Jurassic strata in turn have been tilted, faulted, and locally folded, and very deeply eroded. Only a few hundred feet of the conglomerate remain in this outlying formation, but the sediments are similar in all respects to the conglomeratic sandstones forming the basal members of the series at many other places. Much better opportunity was found a few miles south of Tsetsenwan to determine the great thickness of the whole formation, but in the northerly outliers were found the first clear evidences of the great erosion break that lies beneath them. Elsewhere this formation is folded in much the same manner as the graywacke series, and except for some such exhibit as this, the importance of the structural break between them would not have been so apparent.

It is difficult to reconstruct the topography of the country when the Jurassic strata were laid down. The most suggestive thing about it is the fact that on this old floor there was deposited an enormously thick series of conglomerates and quartz sandstones. Wherever the floor is visible, it looks sufficiently uniform to have been a peneplane, but it is clear that the thick beds of pebbles and sand were washed down upon it from fairly rugged hills. There is no evidence whatever of marine influence. Throughout the Gobi region the Jurassic strata lack marine fossils, and, so far as seen, contain only a few plant remains. It is a striking feature of the geologic history of Mongolia that, from the time of the deposition of these continental conglomerates to the present, there is no evidence whatsoever of marine invasion. We conclude that the region has been continental since the great conglomerate-sandstone series first began to form, at some time in the Triassic or early in the Jurassic period.

A side traverse to the south of Tsetsenwan

On May 29, a side traverse for a distance of forty-five miles was made to the south of Camp Tsetsenwan, in order to extend geologic observations across the structure of the country (Fig. 40).

The geologic formations crossed in the course of this southerly traverse included an exceptionally good display of the strata that lie on the old eroded granite floor. The first two miles of the trail led across the fan at the foot of the Tsetsenwan mountain block, and in that distance no trace of the rock floor could be seen, although there is little doubt that it is the same granite which emerges from beneath the edge of the fan a little farther on. From mile 5 to mile 8 the trail lay across the eroded edges of a portion of the graywacke-slate series which represents a roof-pendant wholly surrounded by granite. This block of graywacke has no topographic expression, except that outcropping ledges are a little more frequent along that portion of the trail than on the granite. In some places it is very greatly modified by contact influences, undoubtedly originating from the granite bathylith. Beyond this the trail lay for three miles over bare granite with the usual dikes; but from this point onward the graywacke and slate roof again forms the country rock continuously to mile 20, where the first conglomerates were found, lying unconformably on the deeply eroded graywacke series.

The first patch of conglomerate, less than a mile in extent, is only an outlying erosion remnant, occupying the bottom of a shallow syncline. Beyond it the broad anticlinal arch is completely denuded, so that the graywacke series peeps through and forms the surface again. From mile 21.5, however, for a distance of twenty miles, sedimentary formations of Jurassic and later age are crossed continuously. For the first ten miles, the strata, consisting of conglomerates and sandstones of exceedingly great thickness, clearly belong to a single formation. The basal members are heavily conglomeratic and obscurely bedded, while the higher members, consisting chiefly of sandstone, are clearly stratified. The dip varies from only a few degrees to as much as 60 degrees at different places within this ten-mile section. For the first five miles, the dip gradually increases from a scant two or three degrees where the basal members are first encountered, to 30 and 35 and finally to 60 degrees; over the first three miles the rocks are chiefly conglomerate, and over the last two, dominantly sandstone. Beyond that point the sandstones continue with varying dips, for five miles.

In general, the dip is to the south throughout this whole distance, and as far as could be determined there is no repetition of the individual beds except at one point, near mile 30, where there is a possible reversal of dip for a short distance. If it be true that there is no repetition of beds of any consequence, the section represents an enormous thickness of strata. There is a total distance of ten miles before any change of formation takes place, and the average dip must be close to 30 degrees throughout the distance. On this basis, there must be no less than twenty or twenty-five thousand feet of strata, all conglomerates and sandstones. For long stretches the trail passes over bare, thin-bedded sandstones standing on edge in so simple and so well-exposed a condition that no important change could have been overlooked. The inspection, of course, could not be exhaustive, but the fact that no fossils were found in such extensive exposures of strata, largely quite open to observation, shows that the formation is unusually barren. There is no way of telling the age. These strata are referred to the Jurassic period on the same grounds as those which previously have been relied on for conglomerates and sandstones of this type. They are undoubtedly the same formation, and were at one time doubtless continuous with the remnants found ten miles north of Tsetsenwan, where plant remains were found in some abundance in basal conglomerates of the same sort. It is possible, of course, that no portion of this series is of Jurassic age, but the number of other possibilities is not great. There is everywhere an unconformity above this conglomerate-sandstone series, and the lowest formation above the unconformity, as we afterwards learned, belongs to Lower Cretaceous time. It is clear, therefore, that these strata must have been formed long enough before the beginning of Lower Cretaceous time to allow for deformation and profound erosion. It is probable that, in part, they reach back into the Triassic period, but Palæozoic possibilities are eliminated by the discovery that the Permian was a time of marine deposition, and strata of that age carry abundant marine fossils. Profound deformation, followed by extensive erosion, then preceded the deposition of this formation.

The conglomerate-sandstone series, therefore, which represents the continental type of deposit, must have developed in the time intervening between two profound breaks in the column, one at the end of the Palæozoic era, when changes occurred which transformed the region into a continental area, and the other, just preceding Lower Cretaceous time, when the last mountain-folding took place and the last great unconformity was developed. Perhaps the series is in part Triassic and in part Jurassic, but it has the same significance in either case. For simplicity, it is convenient to refer to this formational series as of Jurassic age.

At mile 31.5 to mile 32, the trail crosses a complex of eruptive porphyry (Fig. 41). The rock is dense, brittle, much fractured, variable, with little regularity of structure. It is not clear whether the rock should be regarded as part of the Jurassic formation just described, or part of the volcanic series to follow, or, yet again, a part of the older floor unrelated to either. At the time of making the traverse these porphyries were considered as being in all

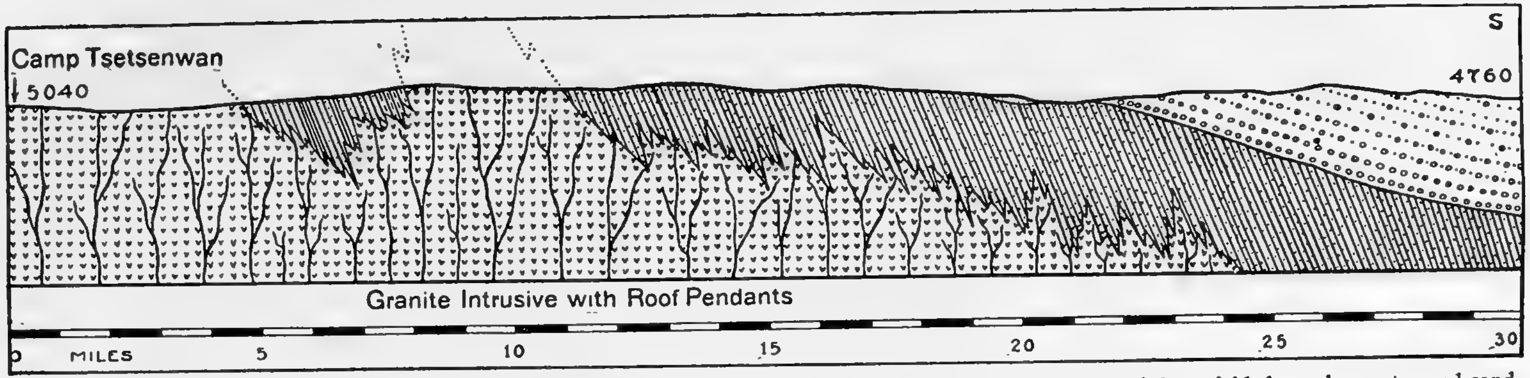


FIGURE 40.—Side traverse southward from Tsetsenwan across the exposed granite and its roof to an area of down-folded conglomerates and sandstones, judged to be of Jurassic age. The unconformity at the base of the conglomerates marks one of the greatest erosion breaks in the whole geologic column of Mongolia.

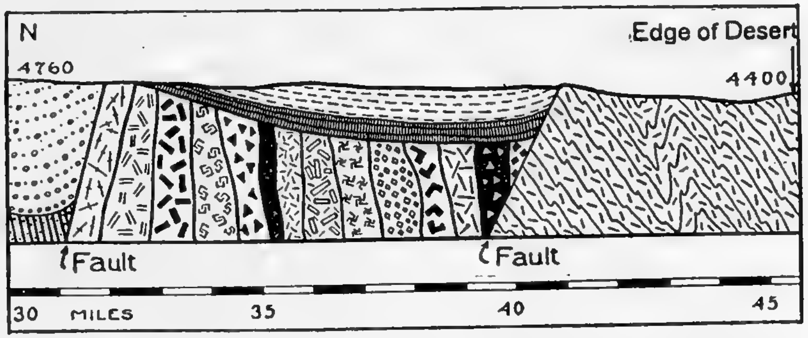


FIGURE 41.—Continuation of the side traverse southward from Tsetsenwan across fault blocks involving the Jurassic conglomerates, a complex of older porphyries, and very ancient gneisses. In one of the fault block depressions younger sediments and volcanics are preserved.

probability a part of the Jurassic series, representing flows and intrusive sills of that time, which have shared the deformation affecting the whole system, and so have taken on some of the complexities of structure, especially a peculiarly fractured condition. This explanation seemed reasonable in view of the fact that the porphyries, whose structure could not be clearly made out, are succeeded immediately on the south by a great series of volcanic flows, breccias and tuffs, with associated sills and reworked ashes, which dip southward at first, in much the same manner as do the Jurassic sandstones. They are much less consolidated, however, and, in the absence of any evidence as to their age, it is quite impossible to determine whether this volcanic series really belongs to the Jurassic formation or to an entirely different and later one. Later experience in other localities led us to consider that they may be of Cretaceous age, or even younger.

The volcanic series forms a simple syncline for a distance of six miles, and represents again an enormous thickness of material. The beds begin with a dip of 30 degrees to the south, but this is much flattened toward the bottom of the syncline and is completely reversed on the other limb. The total exposed thickness is probably five thousand feet.

On the south, at mile 38, the country is comparatively smooth, where the series passes beneath a cover of uncertain character. The chips of rock seen on the surface do not resemble the volcanics seen farther north, and probably in this shallow basin from miles 38 to 41, there is a thin cover of later sediments not belonging to either series just described.

After crossing three miles of this covered ground, an abrupt change was encountered. Sheared porphyritic granite, granite porphyry and gneiss, with a prominent internal sheared structure, form the floor, all well exposed in a trench marking the outlet of the basin. This abrupt change undoubtedly marks a fault. The ancient floor is brought to the surface again, and the broad sedimentary block crossed in the last twenty miles is at that point sharply terminated. If the whole block to the north belongs to the Jurassic formation, there may be an enormous displacement along this fault line. The whole of the sandstone-conglomerate series is cut out, either here or farther back along the traverse at mile 32, where the complex porphyries were first encountered. In either case, there must be great displacement along the fault at mile 41, or at mile 32, where the porphyries have broken through, or, perhaps, at both places.

The chief reason for considering that the volcanic series, from miles 33 to 38, belongs either to the Jurassic or to the Cretaceous, is the fact that the series is gently folded. The strata form a simple syncline quite consistent with the gently arched structure of the sandstones and conglomerates of the northerly edge of the block. Elsewhere in the Gobi region, folding on such a scale has not been seen in formations later than the Cretaceous. At Camp Jurassic on the Urga trail, an anticlinal fold affects the formations, which overlie the Jurassic strata unconformably, forming an arch several miles across. Perhaps this is a similar structure,—it is certainly not very often found in strata of Tertiary age.

With some authority, therefore, for the latter interpretation, and with the support of observations made elsewhere in the Gobi region, we are inclined now to regard this sedimentary block as being made up of four different units:

1. A simple conglomerate-sandstone formation, of Jurassic age.

2. An eruptive outbreak of porphyries, probably along a great fault line at the southerly edge of the Jurassic block.

3. A group of sediments, with volcanic flows and ashes of probable Cretaceous age, gently warped rather than strongly folded.

4. A very thin local accumulation of later basin sediments.

Beyond the fault at mile 41, the traverse crossed an exceedingly complex series of granites, granite gneisses and shear schists of strongly metamorphosed character. They are doubtless representatives of the most ancient formations and are comparable to the T'ai Shan series in China (Willis, 1907, II, page 1). The amount of internal deformation is striking. All are crushed and sheared to greater degree than was found in any other district. Perhaps this structure, however, can be over-emphasized in its bearing on the question of age; some part of it may be connected with the faulting of the Jurassic block. But the important feature is the occurrence of a great granite gneiss series with schists of largely dynamic origin, quite different in all respects from anything seen since leaving the Urga trail, nearly 200 miles back on the traverse.

CHAPTER VI

FROM TSETSENWAN TO SAIN NOIN AND THE ARCTIC DIVIDE

WESTWARD FROM TSETSENWAN

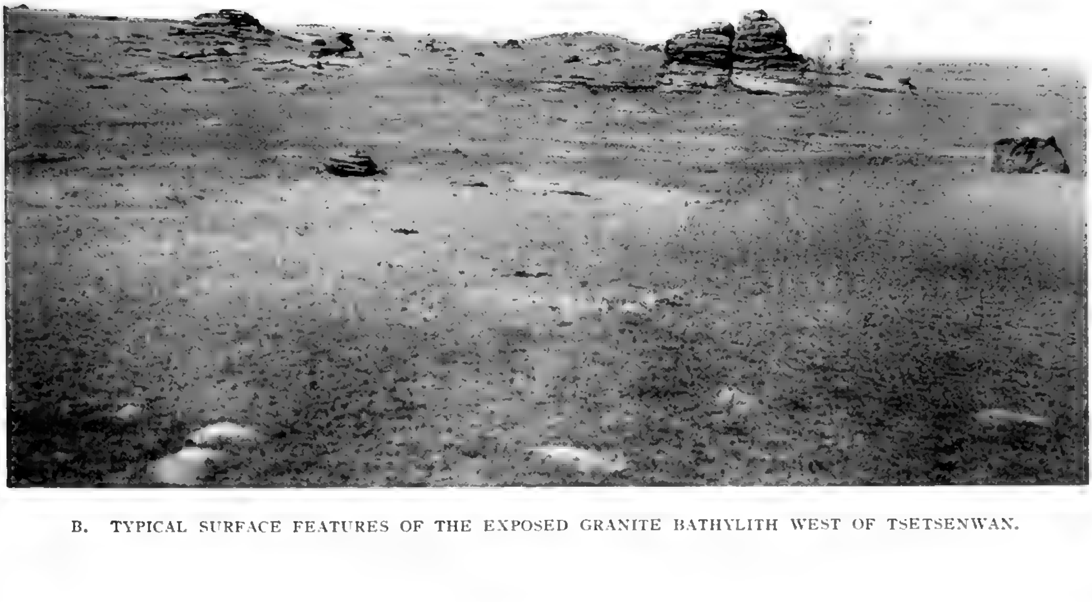
For the first half mile westward from Tsetsenwan beyond Camp Tsetsenwan, the trail lies across the alluvial fans fringing the north edge of the granite mountain block. Then it turns and rises abruptly to the block itself, and for many miles crosses a more rugged country belonging to this structural unit. The principal formation is granite, of coarse to medium texture and of essentially the same composition and general appearance as has been noted at many other places. It is doubtless a portion of the exposed bathylith. The granite is cut by multitudes of dikes of the serpent-form type, although they are not so numerous here as they are north of the lamasery at Tsetsenwan. There are also numerous small xenoliths, representing remnants and roof-pendants of the older formations which once served as a cover for the granite mass. These are largely hornblendic and siliceous in composition, and have in some cases a markedly schistose structure. They range widely in quality, and may represent several quite separate formations of very different age.

In general structural habit, the rocks resemble those around Tsetsenwan, which have been described in Chapter V. In all essential respects this is a block of the same kind of country, but it stands higher, doubtless due to block-faulting. The uplifted block probably has been eroded to a greater depth, and this may account, in part, for the smaller xenoliths and for their greatly modified condition, as well as for a smaller number of dikes.

This kind of country continues for nearly twenty miles, but at mile 831 a new type of very red granite (Specimen 196, A.M. 9885), is exposed for more than a mile (Figs. 42 and 43). It is a later intrusive, and belongs to the same history as the dikes which cut through the granite floor. It reminds one of the variety noticed in the Mount Tuerin district, where a number of strikingly different granites occur together. These simpler, later granites are not much cut up by dikes and carry few inclusions or xenoliths, although they are in all probability genetically connected with the great granite bathylith itself.

PLATE XII.

A. PENEPLANED GRANITE FLOOR ALONG THE URGA TRAIL.



B. TYPICAL SURFACE FEATURES OF THE EXPOSED GRANITE BATHYLITH WEST OF TSETSENWAN.

PLATE XIII.

A. CANYON BROOK.

An aggraded trench in an ancient dissected fault block of complex crystalline rocks at Canyon Brook. The skyline is the profile of an older peneplane.

B. RAINY GULCH.

Rock terrace beveling complexly folded graywackes above the camp at Rainy Gulch on the Tarmil River.

They must be later outbreaks, representing renewal of activity and surfaceward invasion.

At mile 833 a complete change in the character of the rock floor takes place. The structure is very confused indeed. There is considerable crushing and shearing, and some of the rock is strongly silicified. Much of it resembles the quartzites of the graywacke-slate series, but for some distance not a single good characteristic specimen was secured. Farther on, beyond mile 840, it is clear that the rocks are chiefly sheared granites which have become gneisses. In this respect they resemble the still more ancient rocks which we have correlated with the T'ai Shan system (Willis, 1907, II, page 1).

From such inspection as could be made, it appears probable that a portion of the graywacke-slate series is represented for the first few miles, and that the rest of the block is made up of more ancient gneiss (Specimen 197, A.M. 9886), although there is no apparent unconformity. It is certain, at least, that the larger portion of this ground is occupied by shear-gneisses and schists, made largely from igneous rocks, and that they belong to a much more ancient time than do the graywackes and slates. They may, indeed, be comparable to the gneisses seen forty miles south of Tsetsenwan, and it is not improbable that the two exposures are structurally continuous with one another. No other rocks seen in Mongolia up to this point have shown so much intimate internal deformation. Clearly some of these rocks have been made from simple granites and porphyries, and some of the schists from porphyries also, but there are other members whose origin is quite uncertain. Because of the very extensive brecciation, the ledges in many places break down into small chips on weathering. This further tends to obscure the character of the rock, and makes identification more difficult.

Nowhere have we seen the bathylithic granite as much deformed as are the granites of this ground. We are inclined, therefore, to believe that they represent earlier invasions. At any rate, in the run from mile 840 to mile 843 deformation is extremely prominent. It is possible that these are the very oldest formations to be found in the Gobi, and should be classified with the T'ai Shan complex (Specimens 198, 199, 200, 201, A.M. 9887, 9888, 9889, 9890).

At mile 843, granite of the regular bathylithic type is encountered again (Specimen 203, A.M. 9892). The crest of the range has been crossed, and the trail descends the westerly slopes on the exposed granite, which, farther along, is overlaid by a thin layer of sediment concealing the granite for three or four miles. At mile 848, however, the granite is exposed again, with the usual accompaniment of dikes and xenolithic masses, and this continues for several miles. The trail now lies through a mountain valley in which the wash almost completely buries the rock floor under a coarse pebbly cover, which,

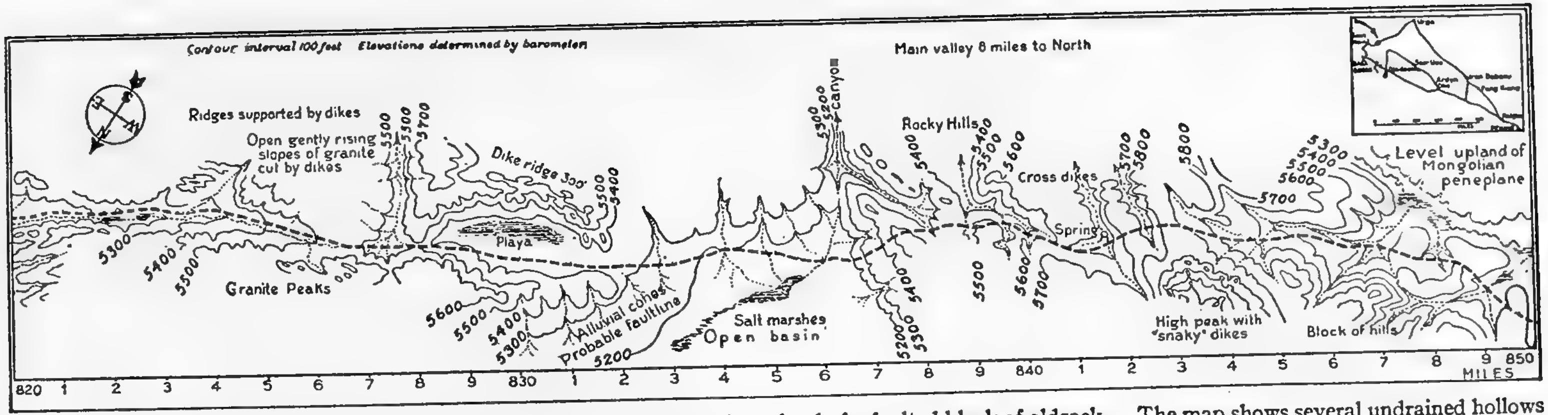


FIGURE 42.—Sketch map of the route covered by figure 43, across the upland of a faulted block of oldrock. The map shows several undrained hollows which have developed in dry stream courses.

The location of this and of the following route maps is indicated by an arrow upon a small index map in one corner, showing the entire route of the Expedition.

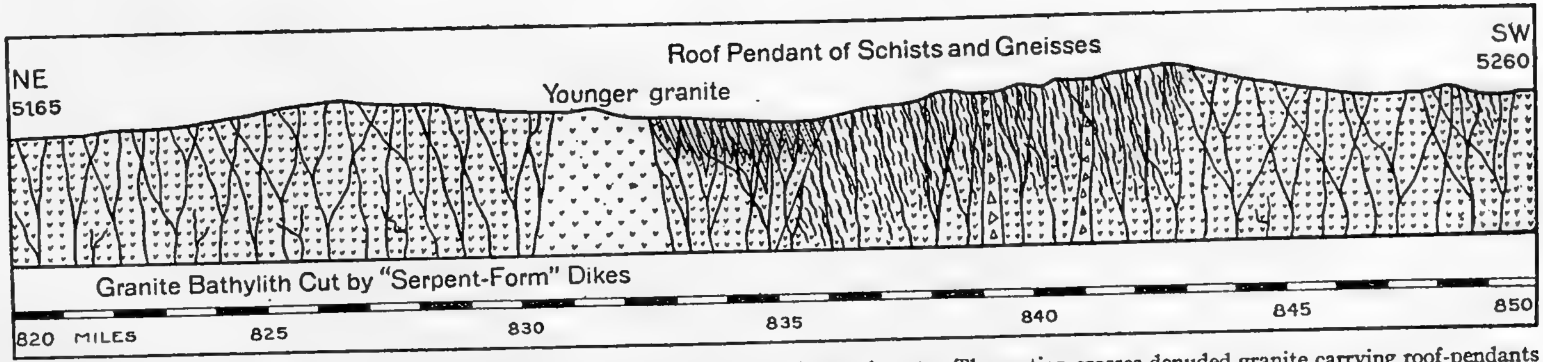


FIGURE 43.—Continuation of the main traverse from Tsetsenwan toward the southwest. The section crosses denuded granite carrying roof-pendants of ancient schists and gneisses. All are cut by multitudes of dikes, with several larger intrusive masses.

in some places, makes traveling extremely difficult. At mile 852, the party turned from the trail into a side canyon, and pitched camp by a mountain brook, which, for want of a local name, we called Canyon Brook (Plate XIII, A).

THE VICINITY OF CAMP CANYON BROOK

A day's stop at this place, where a beautiful stream of pure water comes down the small canyon, gave opportunity for much closer inspection of the rock formations of the locality than had been possible on the previous day. All rocks near the camp are exceedingly crushed and broken. Both igneous and metamorphic rocks are involved in the general deformation, although some of the porphyries have resisted better than other members. Further observations led us to conclude that this spot lies within a crush zone of moderate proportions and that such effects are not characteristic of the whole region.

We examined the canyon for a mile or two upstream, finding a very great range of different kinds of rock (Fig. 44). There are schists cut by red granite porphyry dikes and sills and a complicated lot of associated injections. One of the most prominent members of the series is a broad belt of quartz-mica

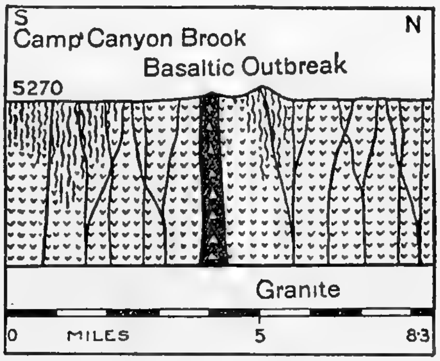


FIGURE 44.—Geologic section of side traverse northward from Camp Canyon Brook.

schist, with which is associated a formation of limestone and limestone schists. Blue and white crystalline limestones occur together; and the structure is complicated by bunches of deformed dikes and other intrusives. All of the members are folded and in some places intimately crumpled. With the limestones there are interbeds of schists, phyllites and quartzites, some of which are graphitic. The general strike of the formation is N. 75–80° W., and in the vicinity of the limestones the dip is 50–60° to the north.

The series must be comparatively ancient, much older than the graywackes and slates that form the major surface rock from the vicinity of Urga westward. How much older it is, there is no means of determining. Its structures are more complicated in all respects, and the series is much more variable in composition and much more metamorphosed. The basis is a sedimentary series of the usual succession of original sandstones, shales and limestones, which have been metamorphosed and extensively injected and cut by igneous masses. Subsequently they were all subjected to extensive deformation, including mountain-folding and crushing. Apparently, crushing is the latest important effect, and this is probably connected with block-faulting.

The series must be very extensive since we found no repetition of beds. Because of the dominance of sedimentary formations, and the fact that some of the limestones are only slightly metamorphosed, we believe that the series is older than the graywacke-slate series, and probably corresponds to the Wu T'ai system of China. We saw virtually no limestones in the graywacke series proper, but in this series limestones and quartz-mica schists are common, whereas typical gneisses are rare or wanting. At Canyon Brook, much more of the terrane is igneous and the rocks are more highly metamorphosed than in the graywacke series.

The canyon opens into a broad lowland, chiefly underlaid by granite of supposed bathylithic relations, and cut by many dikes. In a side trip of about eight miles across the lowland and to the north, we saw two hills which deserve special description. The first is a roof-pendant of older rock, such as has been described as occurring in the canyon. It stands above the valley simply because it is more resistant to weathering than is the average granite of the floor.

The other hill, which is perhaps a third of a mile long and 500 feet wide, is igneous, and represents a volcanic outbreak through the granite floor. It is an olivine-aphanite (Specimen 206), with a strong platy structure, which gives it, at a distance, almost the appearance of a sedimentary rock. This peculiarity of structure seems to have attracted the attention of former inhabitants of the region, who seized the opportunity which these blocks presented for carving inscriptions. On several of them are remarkable drawings, quite unlike the work of the Mongol people, both in subject and in method of making the incisions (Fig. 45).

It is evident from the physical condition of this rock that it belongs to a period entirely different from those with which it is now associated in the district. It is practically fresh, and quite unaffected by the shearing and recrystallization which is so prominent in all of the older formations. It is another of the occurrences of later igneous rocks which were encountered at many places, sometimes associated with formations whose age can be determined. This one is quite without such relations and indicates only that igneous activity of later age extended into regions quite beyond the reach of the typical sediment-basins and far into the foothills of the mountains.

In this traverse across the lowland, one soon discovers that the alluvial deposit, which at the mouth of the canyon seems to be important, is a comparatively shallow accumulation and not nearly as extensive as it at first

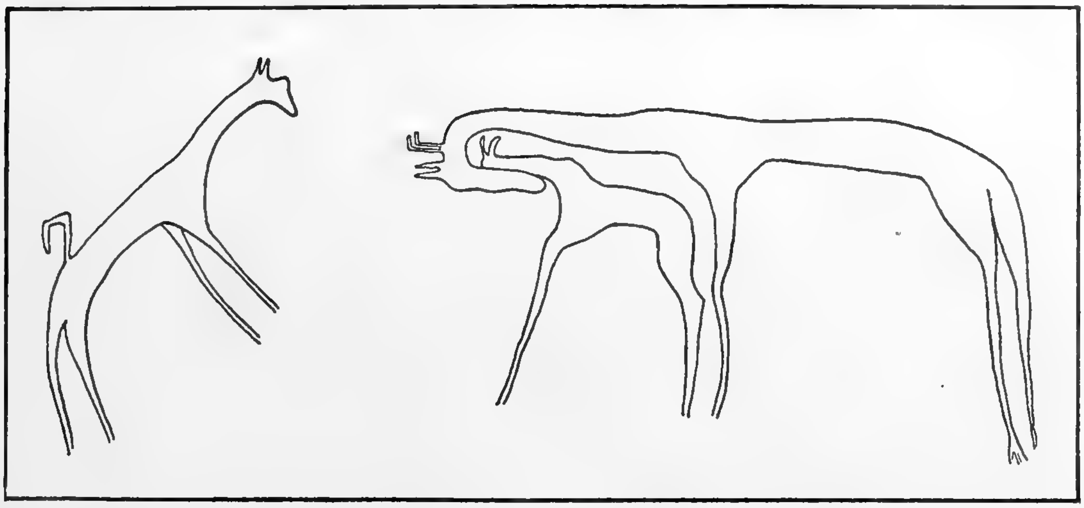


FIGURE 45.—The rock drawings near Canyon Brook were found at the dolerite hill shown on figure 46. They had been incised with a sharp stone tool upon natural slabs of dense black dolorite. The horns of the mother, and the short, lifted tail of the single figure, suggest the antelope.

appears to be. The granite floor is well exposed at many places, and small irregularities of the floor appear as completely bare outcrops (Fig. 44).

The character of the alluvium attracted some attention. It is composed of an unusual proportion of large pebbles, some approaching bowlder size, which have been spread far out into the valley. In addition, the deposit is terraced, and the whole setting raises a question of the competence of the present small stream to accomplish such extensive work. There may be times of the year, of course, much more favorable to transportation than early summer, but under the best circumstances it does not appear likely that the present climatic conditions would present sufficient water-supply for so enormous an accomplishment. Perhaps there have been times more conducive to the transporting of such heavy material. This inference is somewhat sustained by the terraced condition of the deposits.

The dominance of worn bowlders and pebbles led at first to the suspicion that ice had played an important part in transporting the material; but this hypothesis was later abandoned as unsupported by any evidence of glacial work on the adjacent ground (Plate XIII, A).

FROM CAMP CANYON BROOK TO THE ONGIN GOL

The party left this camp on Thursday, June 1, 1922, with a recorded mileage of eight hundred and fifty-four miles from Kalgan, and made a run of forty-six miles during the day to the crossing of the Ongin Gol (Fig. 48).

The route lay across the open lowland for a distance of eight miles, over the alluvial deposits already referred to, with an occasional hillock of bare rock standing above the general level. These in some cases are roof-pendants of the older meta-sediments, with their typical crushed and sheared igneous members, but most of them are surrounded by granite which appears to form the major portion of the floor just as was found in the side traverse of the previous day. There are granites associated intimately with the older rocks whose relations seem to indicate that they also date from a more ancient time than the bathylith. They are crushed and sheared with the meta-sediments, whereas the bathylithic granite, forming the major floor, is comparatively free from such deformation (Fig. 47).

A number of xenoliths and roof-pendants of these older rocks are encountered within the valley and on its westerly margin. The trail then passes into the upland that divides this valley from others tributary to the Ongin Gol, the highest point in the first range being 700 feet or more above the valley of Canyon Brook. On this traverse the whole series of modifications, which mark the transition from a roof of ancient rock to the invading, underlying bathylith, is passed in review. At first, on the margin of the valley, the old meta-sedimentary series is dominant; but outbreaks or injections of granite are encountered repeatedly, and finally they become close-set, *lit-par-lit* injections, making a complex of oldrock types and intrusive granite, so commingled that it would be impossible to determine which type predominates. In many places, therefore, the rock is an intimate mixture, a compound rock, not capable of simple classification. It is a variable injection-gneiss. In some places the injected portions are porphyritic; in many others, they maintain the flow structure of the invading material; and in others there is a partial preservation of the original structure of the older host rock. Effects of this kind are exhibited in great variety. As there is little soil cover, the rock is almost bare, and so there is no mistaking the facts of structure. Nowhere in the whole Gobi region have we encountered a better exhibit of the intimate interrelations and complexities of product that may be made by the invasion of older metamorphic rocks by younger igneous magmas.

It is in this region, also, that several other striking features were first seen, such as fine white porphyry dikes, wholly lacking in ferro-magnesian content, and looking almost like pure quartzite. Here, too, the porphyritic varieties of granite were first definitely proved to be simply a facies of the major bathylithic mass.

Rock-bound hollows

One of the most striking physical features belonging to the locality is the occurrence of small, rock-bound hollows entirely within the granite. Not

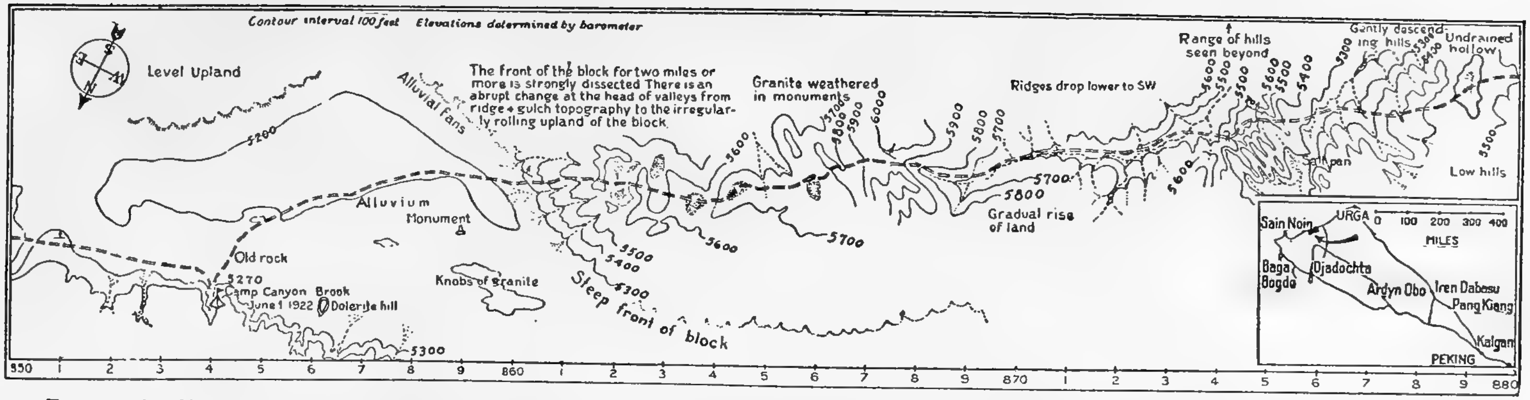


FIGURE 46.—Sketch map of the route covered by figure 47. The map shows two upland blocks, separated by a lowland of hard rock, thinly strewn with alluvium. The outstanding features are the abrupt fronts of the blocks, dissected by short and steep gullies, and the gently rolling upland surface, in which are a number of undrained hollows. (Compare with field sketch, figure 36, pages 98–99, showing the front of a similar block at mile 815.)

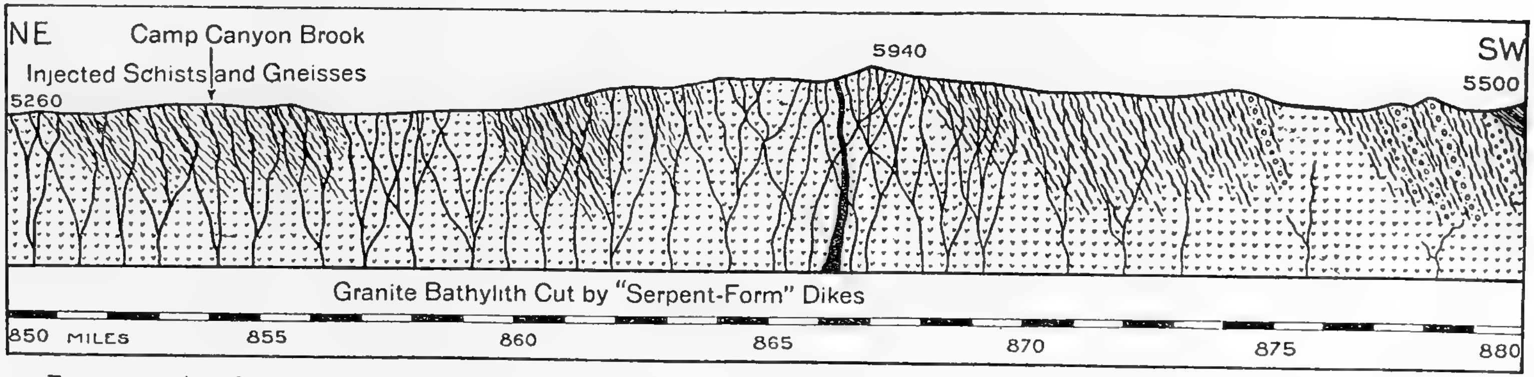


FIGURE 47.—A typical zone of contact between the underlying granite bathylith and the rock formations of the roof. The former downward extension of the folded schistose rocks has been destroyed by the upward encroachment of invading bathylith, leaving an irregularly jagged contact.

only are they surrounded by granite, but undoubtedly they are floored with the same rock. Some of the shallower small hollows are dry, but the deeper ones, in June at least, are partly filled with water. In the shallower hollows the floor rock is badly broken up, the ground being strewn with blocks of granite in hopeless confusion.

At first we were inclined to ascribe these hollows to the gouging action of ice, but the failure to substantiate the occurrence of ice of any such capacity, or to find any deposits that might have belonged to such an agent, led us to abandon that hypothesis entirely. There is no evidence of local deformation with which they could be connected. There is no outlet for water, and under these conditions only ice or the wind could transport the material. There is no chance for solution to accomplish much in such a rock, so that sink-holes are out of the question (Fig. 46).

It is very noticeable that the coarser-grained bathylithic granite has a distinct tendency to disintegration. As we had already noted at many places, great blocks are tumbled about in utter confusion; and apparently the process of breaking down to finer and finer particles goes on uninterruptedly, reducing coarse fragments to smaller ones, even to sizes that the wind can carry. Evidently certain spots yield to extreme disintegration more readily than others, and these places have been etched out deeper and deeper. Weathering furnishes the first step, and the transporting power of the wind completes the process by sweeping the ground virtually clean.

Climatic changes, however, must have affected the process to some extent. Disintegration and removal could not have been accomplished under water, and evidently the hollows now containing small lakes could not have been made under present conditions. The hollows, however, might have been made in a more arid time, and they may be subject to repetition of the process if the climate should change again. We judge, therefore, that they have been formed by deflation and that they have significance in the problem of climatic change. It is certain that some superficial process is responsible for them, and the only agencies capable of making these hollows seem to be the wind and the weather. The hollows and their meaning are discussed in later chapters of this report.

Continuation of the traverse

The bathylithic granite continues for several miles to the top of the range, but after passing a short distance beyond the summit, the metamorphic rocks belonging to the roof are encountered again. In the next ten miles we crossed a series of ancient metamorphosed sediments more complicated and interesting than those in any other stretch of equal length in our itinerary; but the work was done at a terrific pace, and under these circumstances the full significance of the rocks could not be determined. It is most unfortunate that there was not more time for this geological work, for the section exhibited here is regarded by us as one of particular significance, and would well repay more detailed study.

For the first five miles the rocks are intimately intruded, giving a great series of injected and granitized gneisses. The major basis, however, is a series of schists and phyllites, and the final product is a complex of these ancient meta-sediments plus the injected material.

At mile 874, we saw the first conglomerate of importance, much sheared and metamorphosed, and evidently belonging to a very ancient formation. The whole succession to this point probably belongs to the same series of formations that were described at Canyon Camp, twenty miles back. The significance of the conglomerate, however, was not fully determined in the necessarily hurried reconnaissance. Whether it is a true basal conglomerate of a system, or simply an intraformational conglomerate, we do not pretend to say. It is certain, at least, that the succeeding formations of the next four miles are in a simpler physical condition. They are chiefly slates and phyllites, and there are many interbedded conglomerates. A slaty condition is especially prominent as the higher beds are reached. It is possible, therefore, that, in the beds crossed from mile 877 to mile 879, an overlying formation, younger in age than the outcrops farther back on the trail, is represented. On this evidence, we are inclined to represent two different series of formations. Another interpretation requires that originally a highly variable group of sediments existed in this locality, with several conglomerates separated by finer-grained beds; that later on, the finer-grained members were metamorphosed into phyllites and schists; and that, where certain of the schists were reached by the invading magma of a large igneous body, they were transformed into injection-gneisses.

At mile 879, a still more pronounced change takes place. Fine-grained phyllites, which look almost like slates, predominate. They give the impression of being a much simpler formation than the conglomerate-bearing series covered in the last ten miles; but the exact structural relation between the two could not be determined. It was noted, however, that the dips of this formation are gentler than those of the other formations; and we judged that there is an angular unconformity between them. At mile 881, granite breaks through this series also, and forms the surface for a short distance; but half a mile farther along, the whole floor is covered by Jurassic strata which come in on top, in the form of a shallow, synclinal remnant extending for about six miles (Figs. 48 and 49). West of the Jurassic remnant, we encountered argillites and graywackes of structure so broken that the dips are obscure, instead of the plainly bedded phyllites seen ten miles farther back;

and from this point onward to the Ongin Gol the country rock is continuously the graywacke series.

It appears, therefore, that a decided change of formation has again taken place, either beneath the synclinal covering of Jurassic strata or back at the eastern edge of the phyllite area, where the unconformity is drawn in the cross-section (Fig. 49). We judge that the phyllites at the eastern margin of the Jurassic syncline belong to the graywacke series and that these beds are simply the lower members of it. We are satisfied from petrographic and structural field evidence that the other formations still farther east belong to older series. This is the only place in the itinerary of the summer where these two series are so well exposed and where there is so good an opportunity for determining the exact relations. It would undoubtedly be possible to work out the structure and determine relations in detail; but the whole ground was covered by the Expedition in half an hour, and some of these critical structures escaped direct observation.

For the next fifteen miles the ground descends very gradually to the valley of the Ongin Gol. The lower ground is covered with soil and the rock floor is seldom seen. There is, however, no real doubt of the continuance of the graywacke formation for the entire distance to the Ongin Gol.

At mile 895, there is an outbreak of dolorite, in the form of a dike, sill or plug. It has resisted erosion much better than the surrounding graywacke, and makes a prominent landmark standing perhaps 200 feet above the average level (Fig. 48). This is only one of a chain of four or five hills stretching away in an almost straight line toward the northwest, as though they all might belong to a single body whose course is marked out by these remnants. The material is an exceedingly tough and durable aphanite of doleritic composition, not very different in general character from that seen in the valley adjacent to Camp Canyon Brook.

The Ongin Gol

From the Khangai Mountain range, which forms the Arctic divide farther to the north, the Ongin Gol flows southward toward the desert. At mile 900, the river occupies a valley several miles wide, within which a still lower trench about a third of a mile wide is cut. Within this lower portion, the river maintains a braided form due, as usual, to the amount of sediment carried to this part of its course. The stream occupies only a small portion of the total width of the inner valley, though it is evident from the form of this bottom-land that the river has occupied different portions of it at different times. The upper, wider valley is apparently not heavily covered with river deposits, although rock is not exposed at many places. The inner valley

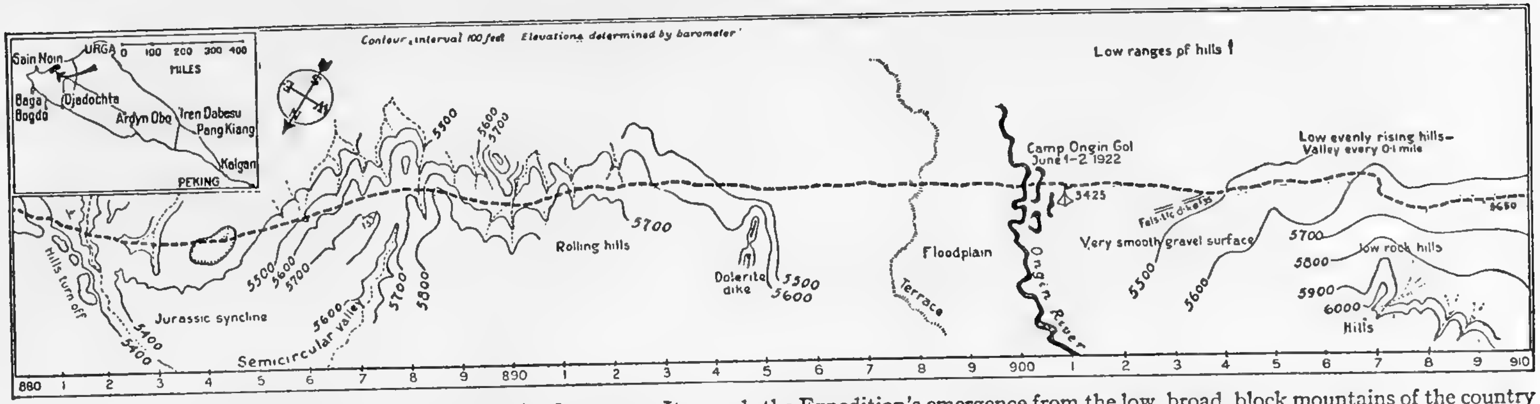


FIGURE 48.—Sketch map of the route covered by figure 49. It records the Expedition's emergence from the low, broad, block mountains of the country westward from Tsetsenwan, into the flood plain of the Ongin Gol. The "semicircular valley" between mile 882 and mile 887 follows the outcrop of a weak bed in the southward-pitching syncline of Jurassic conglomerates and sandstones.

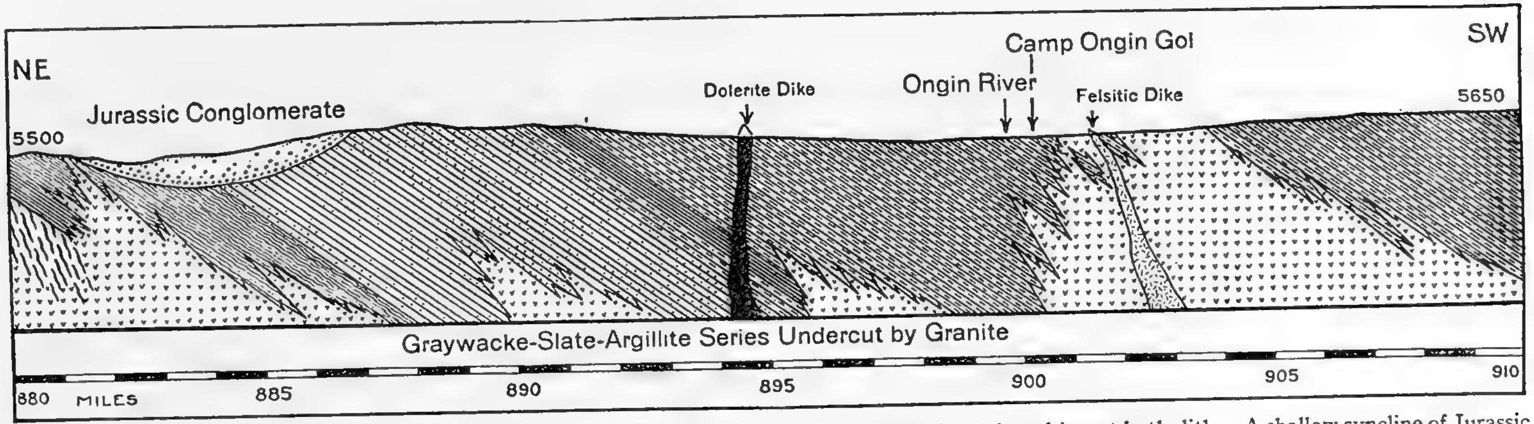


FIGURE 49.—An area of graywackes and slates with local exposures of granite protruding from the subjacent bathylith. A shallow syncline of Jurassic conglomerates represents all that is left of a formerly much more extensive cover.

is cut down into these loose deposits, with a drop of fifteen or twenty feet, and the stream channels cut a little below this.

The Ongin valley, therefore, is a terraced valley, indicating some change in the transporting competence of the river within moderately recent time, and at present it is in essentially graded condition. Subsequently a more pronounced terracing was noticed farther south, where the stream enters upon younger sedimentary strata which are more easily eroded. In that part of its course continuous and prominent terraces of fifty or sixty feet are cut out of the rock floor.

The river had to be forded, and, because of the shifting sand of the bottom, it presented a treacherous ground for motor travel. The geologists' car was hopelessly swamped in one of these distributaries and twisted off an axle, a misfortune which led to considerable difficulty in making the repair, and necessitated some little delay.

FROM THE ONGIN GOL TO SAIN NOIN

Camp was pitched at the Ongin crossing on Thursday, June 1, 1922, and repairs consumed the whole morning of the following day, but by eleven o'clock the Expedition was moving again toward Sain Noin.

On the west side of the Ongin Gol valley rock outcrops are more numerous than had been found on the east side. A short distance south of the camp a large area of coarse-grained, massive granite of bathylithic type is exposed, with large residuary bowlders and remnants, similar in all important respects to the granite areas seen many miles farther back along the trail (Specimen 229, A.M. 9918). It is the first important occurrence of granite that we had seen for twenty miles. The area exposed here extends to the south beyond the limits of the inspection, but to the north the granite area is sharply delimited and other rocks come in. A large dike of felsite makes a prominent outcrop about a mile and a half from camp (Specimen 230, A.M. 9919), and with it is associated granite (Fig. 48). Only a little farther on, however, at mile 904, slates and argillites are encountered again, similar in general type to those seen farther back on the east side of the Ongin.

The course of the trail lay S. 55° W. over a smooth road, easy for motor travel. No side inspections were made, but the hills at a little distance to the north have a form and appearance quite unlike those of granite, and are probably made up wholly of slates and graywackes, belonging to the graywacke formation. Much of the ground along the trail is covered, so that one catches glimpses of bedrock less frequently than was usual on the traverse out from Urga. The ground rises gradually and the country becomes less barren. Indeed there are many stretches which, by contrast with areas crossed

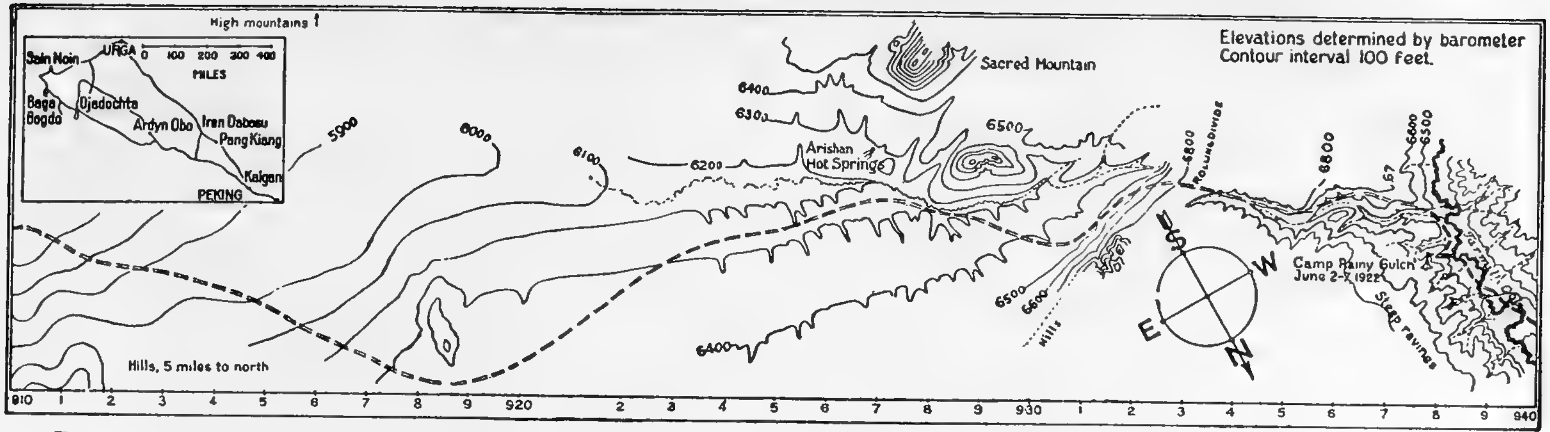


FIGURE 50.—Sketch map of the route covered by figure 51. The valley between mile 923 and mile 929 is mapped on a larger scale in Plate XXVI (in pocket). The Tarmil Gol valley, mile 938 to mile 940, is better shown in figure 52, page 126.

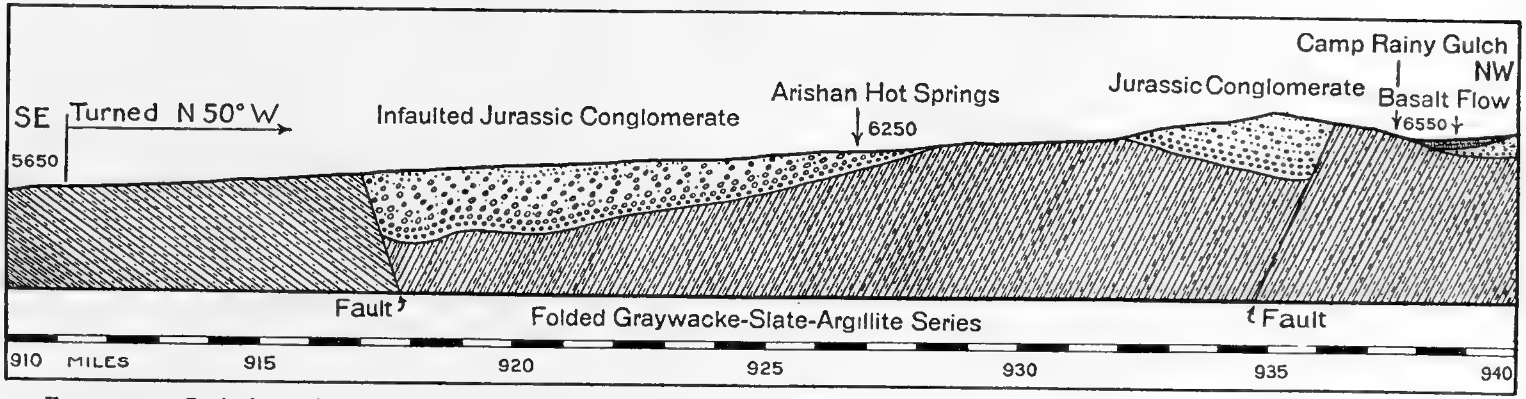


FIGURE 51.—Geologic section from the Ongin River to Arishan hot springs and Sain Noin Khan. The rock floor consists of much deformed graywackes. In the depressed portions of this floor remnants of conglomerates and sandstones, believed to be of Jurassic age, are preserved. Tertiary or Pleistocene basalts choke one of the river valleys.

farther south, look quite fertile. Flocks find good grazing, and it is evident that the region is one of greater prosperity than most of those encountered in the 900 miles of our traverse to this point.

The course S. 55° W. was maintained for eleven miles, to mile 911, and then was changed abruptly to N. 50° W. toward the official capital of the province of Sain Noin (Figs. 50 and 51). The trail lay for several miles over the same open country with the soil-covered slate formation, and then continued through a broad valley bordered by hills on either side. Here and there an isolated hill rises within the valley itself, and one of these, at mile 917, stands one hundred feet above the smooth slope of the valley. The hill is made of Jurassic conglomerates and sandstones, dipping gently northward. The beds form part of a synclinal fold belonging to a down-dropped fault block. The trail had crossed the bordering fault about a mile south of the hill. Northward, the block of Jurassic sandstones underlies the valley for more than ten miles, and in large part controls its width. The hills on either side, not more than three or four miles away, are made of an older and entirely different kind of rock enclosing the down-dropped block. In the midst of this stretch of Jurassic strata, the trail passes near the hot springs and the Holy Mountain of Sain Noin. About a week later a special study was made of this small area, and the structural relations were worked out in enough detail to determine the principal features. (See Chapter XII, page 213, "Arishan, the Sacred Mountain of Sain Noin.")

At miles 928–929, the graywacke-slate series is encountered again, after passing over more than ten miles of Jurassic floor. The rock is badly cracked, jointed and confused; the structure is somewhat obscure, and in many places the bedding cannot be made out at all. Later it was found to be quite variable, and the whole formation, which is cut by dikes of porphyry, shows very pronounced internal deformation. The strike at this point is roughly N. 45° E., with a dip to the north. Only a few miles of the graywacke are crossed by the trail. As the ground rises and a small divide is approached, the trail enters upon another block of Jurassic sandstones and conglomerates, which continues for about four miles. At mile 936, after passing over another fault, the graywacke is encountered again and this formation continues to the new camp at Rainy Gulch, a name given to it in memory of our day's experience (Plate XIII, B).

The vicinity of Sain Noin

The day's traverse from Ongin Gol to the vicinity of Sain Noin was a strikingly unusual one. It was begun in threatening weather, and rain seemed imminent during the whole day. Near the end of the journey, after reaching the small divide, the storm broke full upon the Expedition and we were treated to the most terrific rain experienced in the whole summer. The water came down in torrents, and we could begin to appreciate the effect of such a rain on the barren slopes of the country bordering the desert. With the passing of the storm the trail became treacherous, and a chance for camp was welcomed at a small gulch in the edge of the next valley, that of the Tarmil Gol, which flows northward into the Ongin Gol. On the main stream, only two or three miles away, are the lamasery of Sain Noin and the seat of local government (Plate XIV, B). The valley bottoms are well grassed, flocks and herds are numerous, and more people live in them than we had seen hitherto in any part of the journey. For Mongolia, the region is a prosperous one.

We had now reached a higher elevation than at any previous time in our itinerary, the aneroids indicating elevations of more than six thousand feet. In addition to this, we were within sight of rather majestic mountain ranges lying twenty or thirty miles farther to the north. Peaks with remnants of snow could be seen from the camp. These mountains form the true divide between the drainage flowing toward the Arctic and that flowing southward into the desert. On account of the promising geologic conditions presented by this divide country, it was decided to go beyond the present camp at least another day's journey and to camp in one of the adjacent ranges. This was done after two or three days' work in the vicinity of Rainy Gulch.

While other members of the Expedition studied the people, their customs, and their living equipment, the geologists investigated the complex rock structure of the valley. Patches of Jurassic sediments overlie the graywacke-argillite formation, and in some places there is a simple sedimentary contact between the two, whereas in others there are faults. The graywacke series is much folded, jointed and crushed. For a long distance it forms the hills and mountains immediately northeast and east, which rise to elevations of over one thousand feet within a mile or two, and appear from a distance to be all of the same type. Subsequent examination of some of the higher ranges showed that they, also, are made up of the graywackes. It is the dominant formation of the Khangai range, and its structural habit and petrographic quality control the minor erosional forms of these ranges.

The Jurassic strata of the vicinity of Rainy Gulch are quite conglomeratic at the base, and the cobbles are almost all of graywacke, like the rock of the immediate floor. This is true especially of the beds at the very base, but higher up in the series one finds in addition pebbles of many crystalline rocks. They vary in size up to a foot or more in diameter, and are angular or subangular, rather than rounded. Evidently the immediate floor rock contributed to this material without much transportation. The conglomerates are not very strongly bedded, but the structure is readily determined, and the dip changes markedly from one point to another, showing considerable folding. There is no fossil content whatever.

The structural conditions of the valley are indicated reasonably well by figure 54. It is marked by a graywacke foundation, carrying Jurassic strata, folded, faulted and eroded, with a valley cut out at one edge of the Jurassic block. Subsequent volcanic eruptions poured out basalt, which flowed down the valley, choking it somewhat and oblitering the topographic detail of the valley bottom (Fig. 52). Since that time, erosion has continued and the stream is again channeling its way through the volcanic material. This

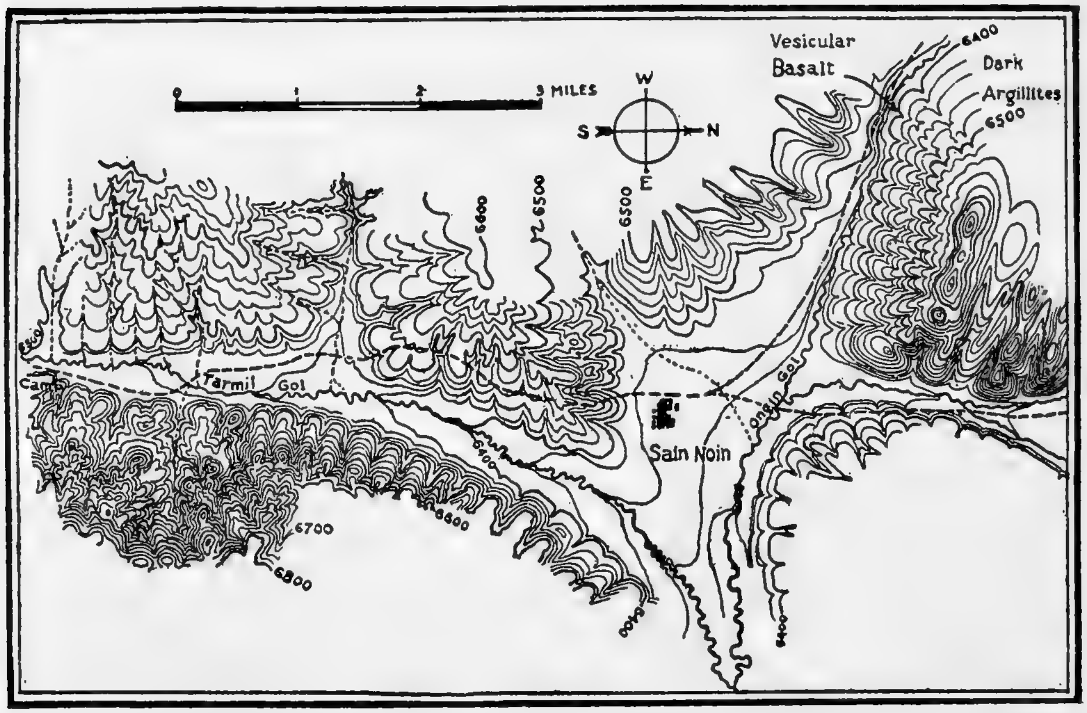


FIGURE 52.—Sketch map of the route in the vicinity of the great lamasery at Sain Noin. The map shows: (1) the flat flood plains of the rivers; (2) a sloping rock bench above the flood plains, separated from them by a low but abrupt scarp; (3) the higher hills rising above the bench. These three elements are especially well shown near "Camp" and north of the word, "Ongin." Note the sudden narrowing of the Ongin Gol valley near the words, "Vesicular basalt," where the river has cut its way through a lava flow which dammed the valley. The narrow ridges just north of the direction-vane are of infaulted Jurassic conglomerates, which stand vertically. From the top of a hill east of Camp Rainy Gulch a sketch was made of the country toward the northwest, shown in figure 149, pages 344–345. (See also Plate XIV.)

basalt out-flow is clearly a very late geological event. The vesicular pumiceous material is virtually fresh.

Jurassic strata, more or less deformed, are found at several places in these valleys at Sain Noin. The occurrences all appear to be remnants of fault blocks, and everywhere they are bordered by the graywacke-slate series. This is true everywhere except where the younger basalts cover the ancient complex, as can be seen just above the lamasery of Sain Noin. One of the impressive things is the comparatively small size of these remnants. Doubtless Jurassic strata of similar character covered most of this region at one time, and only these few patches are preserved after long-continued erosion.

The most characteristic of these, and the one most fully studied, is that at the Holy Mountain of Arishan, where a special areal study was made. This is essentially a graben with a jagged series of bordering faults and a large though uncertain amount of displacement.

Later volcanics were found at three places: (1) a few fragments of vesicular lava at the hot springs near the Holy Mountain, (2) a series of tuffs and lavas near camp at Rainy Gulch, and (3) a basalt lava flow of considerable extent, which fills the valley bottom above the lamasery at Sain Noin. All of these are certainly very late geological products; but they are not associated with strata from which their position in the geologic column can be fully determined. It is very likely that the volcanic outbreaks followed the same weaknesses and belong to the same structural adjustments that mark the graben and block faulting, and we believe that the hot springs are connected with the same history.

All of the lavas are comparatively basic; some are exceedingly vesicular and amygdaloidal, and tend to be porphyritic. Some of the material is fragmental, while some pieces are strictly bombs. One bread-crust bomb was found on the crest of a minor divide, 2,000 feet above the valley carrying the basalts; but, of course, its relations are unknown, and it may have been carried there by man. The lavas are not very extensive or very thick, but at one time they choked the valley bottom, displaced the stream, and modified some of the minor drainage; but the major features were preserved throughout that history, and re-excavation is in progress at the present time.

FROM RAINY GULCH TO THE ARCTIC DIVIDE

The traverse toward the Arctic divide from Camp Rainy Gulch follows the Tarmil River to the lamasery of Sain Noin and crosses the main stream, the Ongin Gol. Thence we climbed to a camp near the top of a minor divide, at an elevation of between seven thousand and eight thousand feet (Figs. 53 and 54). The underlying ancient floor, over most of the distance of sixteen miles, is doubtless the graywacke-slate series, but the first two miles from camp lay across basalt flows that were poured out in the bottom of an older valley. Our trail then crossed a small dividing spur over folded Jurassic sandstones and conglomerates, and across a fault to the graywacke-slates again, into the Ongin Gol valley where basalt flows are exposed. We judged from local conditions that a fault may lie beneath and parallel to this larger valley and that the vent for the lava flows was probably guided by this weakness in the valley bottom. After crossing the river, there was no change in formation to the top of the divide. The rock is graywacke-slate, of more obscure bedding structure, and in a more broken and confused condition than usual. The formation at the divide has a strike of N. 60° E. and dips north at about 30°. As far in the distance as one can see, the hills have a similar appearance, and probably the same formations prevail (Plate XIV, A). In all likelihood the whole range is composed dominantly of the graywacke-slate formation (Specimens 245, 246, A.M. 9934, 9935). It is folded and extremely jointed. There is probably repetition of beds, but this detail could not be worked out. The rocks in general dip toward the north, at a steep but variable angle. There are occasional dikes, but igneous rocks are not very abundant. The formation varies much in quality and is considerably modified, so that in some places it is not easy to distinguish the regular country rock from the medium basic dikes that cut through it.

Camp was pitched in the second grove of forest trees, ten miles north of the lamasery at Sain Noin, just below a very sharp minor divide separating two portions of the Ongin Gol drainage system. It is not the Arctic divide proper. The trail rises at the pass to an elevation above eight thousand feet, and the crest is exceedingly sharp. From it one may look off northward across-country to the real Arctic divide, which lies at the head of the next valley; but bogs rendered it impossible for us to make the traverse across this intervening ground.

We had now reached an entirely different set of physical conditions; we were quite out of the desert and entering the forest country. Indeed, camp was pitched on the very picket line between the forests of the north and the deserts of the south. With the swing of the climatic pendulum to more or to less favorable conditions, this belt must become a fighting zone for occupancy. In certain years conditions must be a little more favorable for the growth of trees and for the lodging and germination of their seeds. If such conditions were to prevail for a considerable length of time, small groves of seedlings would be started on the protected northerly slopes a little farther out toward the desert than usual. With a change of conditions and a return to more arid seasons, growth would be checked and germinating seeds would not survive, so that there would be no addition to the colony formerly established. It might be, though, that the seedlings already rooted could maintain themselves, and remain as an outpost of forest encroachment, to last as long as they could keep their footing.

A return of favorable conditions might permit reseeding of the same ground and enlargement of the earlier-established colony, so that occasionally one might see in these outposts of the forest, groups of trees of widely differing

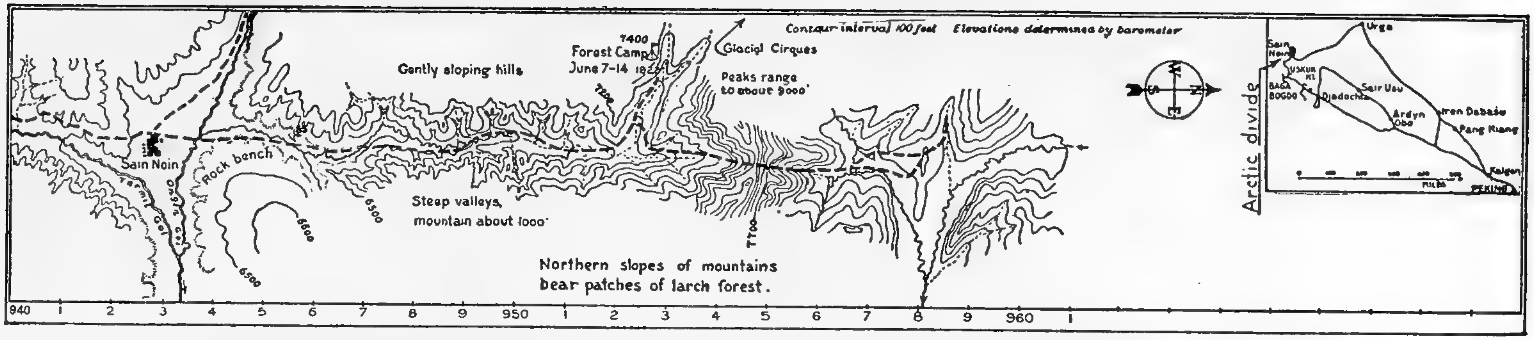


FIGURE 53.—Sketch map of the route covered by figure 54. The northernmost valley, at mile 958, joins the Ongin Gol farther to the southeast. The arrow, marked "glacial cirques," points towards the cirques shown in Plate XIV, B, and in figure 149, pages 344–5. Near mile 945, the strike of the graywackes and their dip, 85° to the north, are recorded by a symbol.

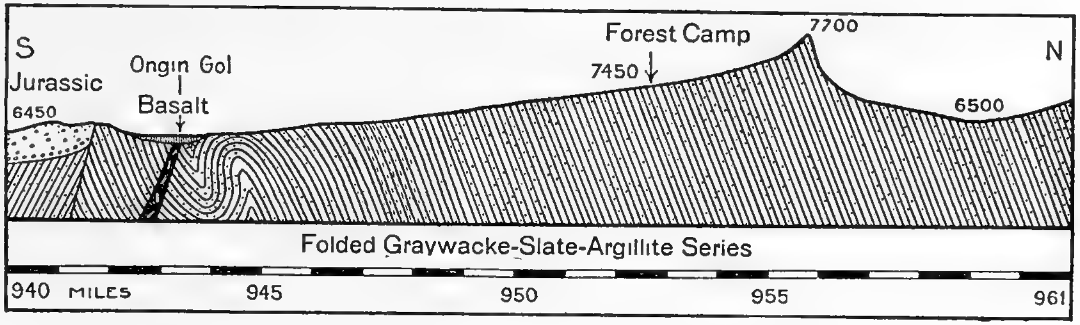


FIGURE 54.—The end of the northward traverse at Sain Noin, in the Khangai mountain range, reaches almost to the Arctic divide. An infaulted Jurassic remnant and a basalt valley-fill are the only features breaking the monotony of the great graywacke series.

sizes. The grove in which we camped, near the divide, is made up of trees of two markedly different stages of development,—a very young growth of seedlings and saplings, and a much older growth of mature trees, more scattering, and apparently the survivors of much hardship. The larch, or tamarack, is the only kind of tree that has been able to persist. Apparently no other is able to maintain itself under these severe conditions. We have found no better explanation for this unusual grouping of sizes than the one just suggested. It has to do with cycles of climatic change.

In many other ways this is a peculiar zone of conflict between quite different interests, conditions and processes. From this point northward the deer is native, and may be found in abundance, with many other denizens of the forest, while southward this fauna is entirely wanting.

Grasses and flowers grow richly, whereas only a few miles to the south the ground becomes barren and such vegetation as may be seen at this spot is unknown. It is, therefore, not only a divide separating the waters of the desert from those of Siberia, but a dividing line where fauna and flora change abruptly; and here one becomes interested in problems which are strange to other parts of the region. It is a critical conflict zone of special biologic interest.

Quite different traveling conditions also prevail. The trails are well marked but treacherous. Miry places are numerous. Wet spots with standing or flowing water are frequent. A stretch of country which appears in the distance to be not only clear but easy, proves difficult and sometimes impassable.

A week was spent in this camp. From it hunting expeditions were made, and deer were taken in the very grove in which the camp was pitched. From that point northward every northern slope is wooded, whereas the southern slopes of ridges and hills are bare of trees. This condition exists as far as the eye can see; but beyond the next divide, well within the zone of forest conditions, even this feature disappears and the region becomes one of continuous heavy forests.

A step across the divide

From this point several splendid cirques, representing glaciation of an alpine type, could be seen at no great distance. It was estimated that they were not more than ten miles away, and on breaking camp it was decided that the geological party should make an attempt to reach these exhibits of glacial action by crossing the divide, pushing up an adjacent valley and down to Sain Noin by a different route. The topographic relations looked simple enough, but an attempt to carry out the program almost led to disaster, for the small tributary valley on the opposite side of the divide was found to be

PLATE XIV.

A. THE ARCTIC DIVIDE IN THE KHANGAI MOUNTAINS.

The upland surface is a peneplane above which rise monadnocks. The southern outposts of the Siberian forests occupy the northern slopes.

B. SAIN NOIN KHAN AND THE KHANGAI RANGE.

Cirques in the Khangai range north of the great lamasery at Sain Noin Khan. Rock terraces are well developed along this portion of the Ongin valley.

PLATE XV.

MONGOL LAMA AND HIS SMALL DAUGHTER AT SAIN NOIN.

quite impassable. After pulling the car out of miry ground several times, it was found necessary to return by the same route. The return journey proved to be one of the most difficult of all the feats attempted with the motors in Mongolia. For the last few hundred feet it was too steep to climb even in low gear, with no load. Everything was unloaded, and the motor driven at high speed and caught with the clutch so that with the help of hard pushing a few feet of progress could be made. This was repeated often enough to reach the summit, which was gained at sundown, with the whole party exhausted. After a brief rest, each piece of equipment was carried laboriously to the top and packed again, but it was then too late to gain camp that night. The main camp had been moved in the meantime to the vicinity of the Holy Mountain, about twenty miles away; so our party slept in the open, along the banks of the Ongin Gol, near the lamasery of Sain Noin. Thus we lost our last opportunity to visit the cirques of the Khangai Mountains.

CHAPTER VII

FROM THE HOT SPRINGS OF SAIN NOIN TO MOUNT USKUK

On breaking camp at Arishan after the special study of the Hot Springs of Sain Noin was completed, the Expedition retraced its steps for a few miles, passing southward down the same valley through which the country had been entered two weeks before. Then the course was changed so as to bear farther to the west in the general direction of Gorida on the old Uliassutai trail (Figs. 55 and 56). For this cross-country journey local trails were used which made fairly good going, but ultimately, at the divide, very steep slopes were traversed which taxed the transport to its limits.

ARISHAN TO GORIDA

The first ten miles led over the southerly extension of the Jurassic fault block represented on the map at the Holy Mountain (Chapter XII, page 213); but at mile 971 the southern boundary of this block was crossed at the fault line (Fig. 56). The strata exhibit synclinal structure, dipping toward the south for the first four miles, and then toward the north for the next six miles, with comparatively sharp up-drag against the fault. From this point to the top of the divide, for the next thirteen miles, a difficult trail was followed across the folded graywacke-argillite series of rocks. All the strata are steeply upturned, the dips commonly reaching 65 degrees, inclining first to the north, and then, after passing the arch of the fold, to the south. In this stretch of country much argillite was encountered, some of it dull gray and dense, and some more highly colored, green and red predominating (Specimens Nos. 255, 256, A.M. 9944, 9945). The whole divide, standing nearly one thousand feet above the valley by which it is approached, is graywacke. Occasional dikes cut the formation, but they are neither very numerous nor very large.

After crossing the divide the trail follows a general course of about S. 60° W. down a broad valley, with considerable alluvial fill. On this slope the graywacke is left behind, and the bathylithic granite, which throughout this country lies beneath all other formations, appears at the surface. One finds,

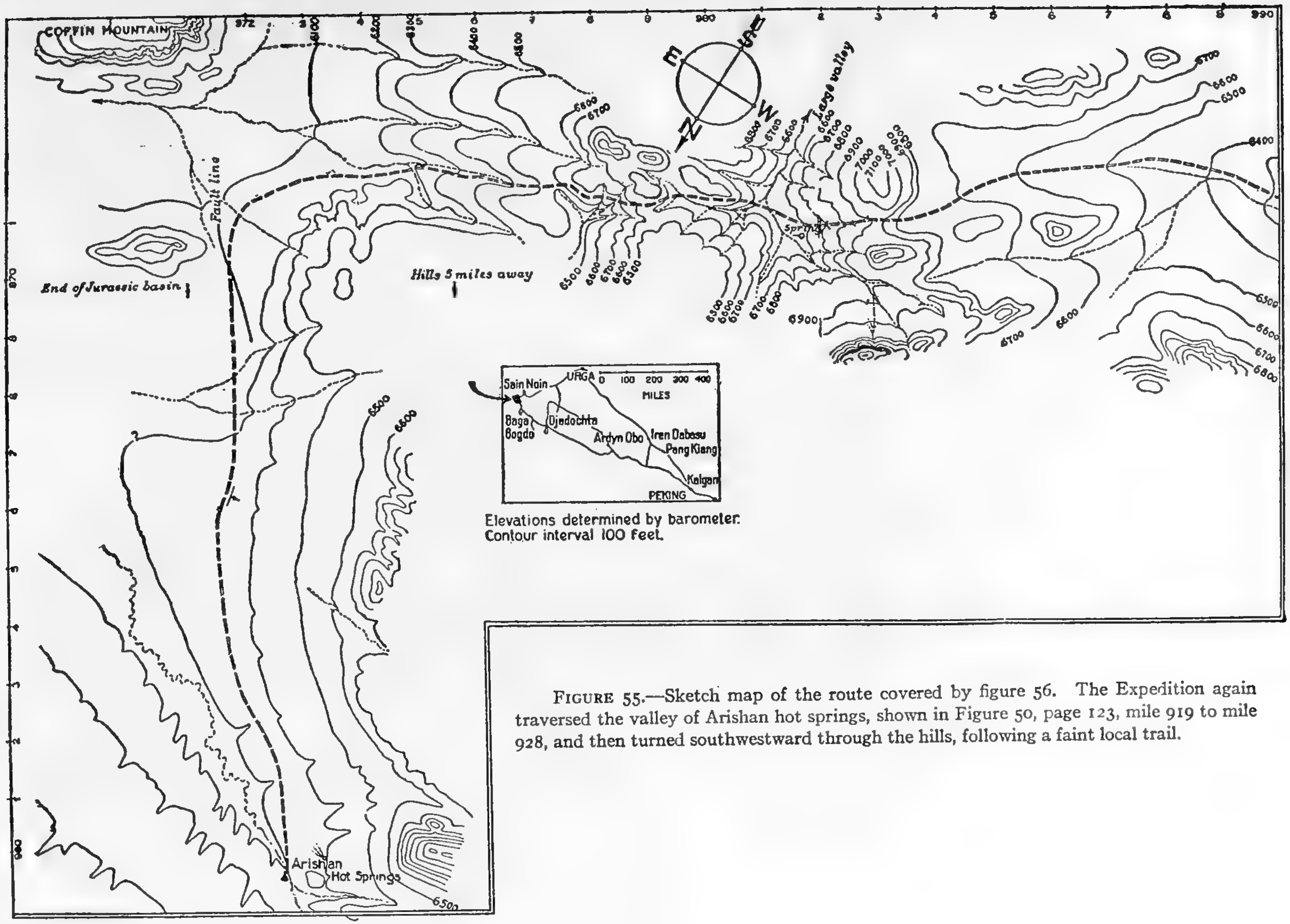


FIGURE 55.—Sketch map of the route covered by figure 56. The Expedition again traversed the valley of Arishan hot springs, shown in Figure 50, page 123, mile 919 to mile 928, and then turned southwestward through the hills, following a faint local trail.

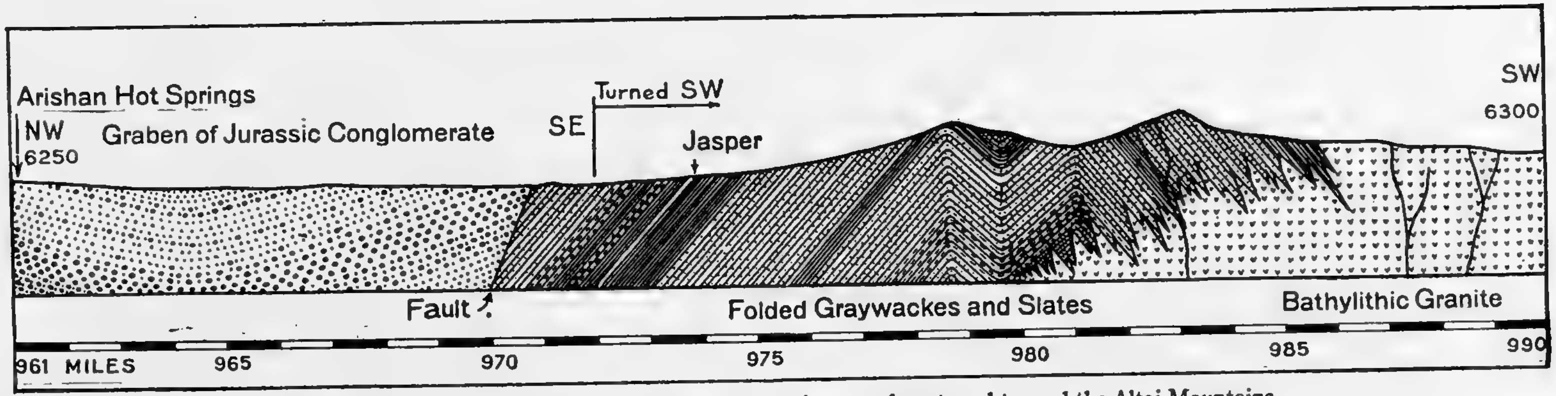


FIGURE 56.—Geologic section from Arishan hot springs southwestward toward the Altai Mountains.

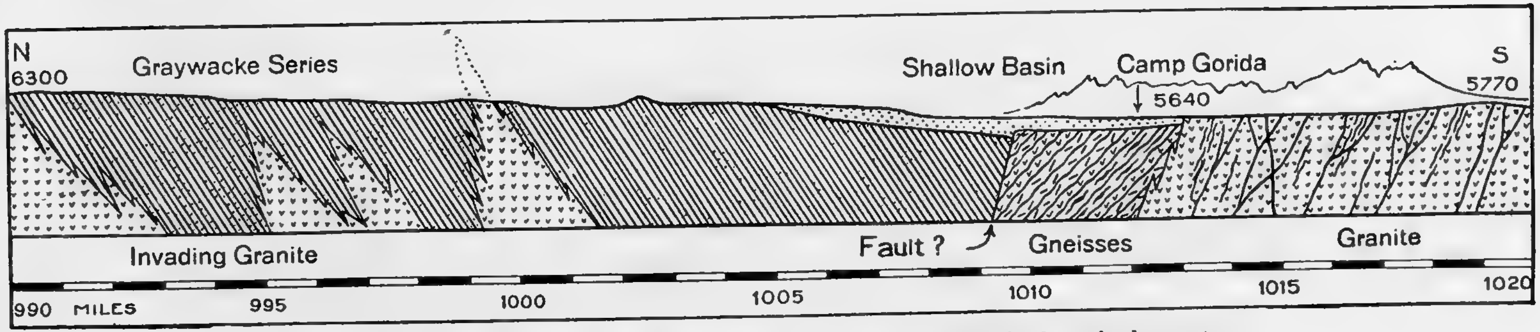


FIGURE 57.—Geologic section from the Khangai arch to the margin of the desert basin country.

therefore, that the graywacke is more and more modified by contact metamorphism with more numerous intrusions, until finally the trail passes over simple granite, cut by dikes. Much of this ground is difficult to read, however, as it is more heavily covered with wash than most of the country traversed in Mongolia. Only here and there could we judge of the quality of the underground without going to the sides of the valley. Subsequent observations tended to support the structure as drawn in the accompanying profile. A continuance of this course, S. 60° W., carried the Expedition off the granite and across fifteen miles more of graywacke (Figs. 57 and 58). The granite bathylith must lie close beneath the graywacke roof, as its projecting intrusive masses break through here and there. Gradually, however, the bathylith passes so deeply beneath that it is not seen at all for the last ten miles.

In this journey down the valley from the divide the course lay toward a most strikingly rugged-looking mountain range (Fig. 59). A very irregular skyline is formed by sharp, jagged peaks, which in the distance appear to stand out in bold relief to great height, but diminish as the mountains are approached. They are essentially granite mountains, and their jagged outlines are due to the disintegration of the crystalline rock guided by prominent systems of joints. There is no regularity of form; but there are precipitous portions and a sharpness of outline that has not been seen elsewhere on such an impressive scale. This is the bathylithic granite again coming to the surface from beneath the graywacke, and we judged that a new fault block had been reached.

The Gorida basin

In the depression lying between the graywacke range just traversed and the granite range to the south, there is a small basin with horizontal sediments belonging to a comparatively late period of sedimentation, although as far as inspected they are barren. At the present time they are being redissected by streams from the adjacent mountains.

West of the small basin an entirely different series of formations is exposed. Ancient gneisses and schists, much older than the graywacke series, are undercut and injected by granite. It is this series that the granite range carries on its flanks. How they are related to the graywackes is not determinable in this region, because the contact zone is covered by the basin sediments lying in the valley between. We have chosen to represent them as shoved up by faulting, but it would be equally possible for them to have been warped up instead. The sharpness of the break, together with the narrowness of the valley, has caused us to prefer the former explanation; and the finding of crush zone material at one point is considered additional supporting evidence for this interpretation.

The intimate penetration of the ancient metamorphic rocks by the granite invasion is shown very well in the vicinity. The mixture is so intimate that it is very difficult to determine how much of the rock is of one type and how much of the other, or what the proportion of intermixture is. Associated with them are schists which strike N. 30° E. and dip steeply to the southeast, forming many low parallel ridges. They are chiefly micaceous and of very fine foliated structure, but there are also amphibolite members. They are shear-schists, and some of them appear to be derived from igneous rocks. They undoubtedly have had a more complicated history than have the rocks of the graywacke series.

The lower part of the valley is covered still more heavily with later sediments, which are not very extensive. They have every appearance of being very late deposits, as they are not indurated or deformed. How recent they are, it is impossible to say. The simple surface form which they represent appears to continue indefinitely toward the south, but in the course of less than eight miles of travel down stream, they completely disappear, and the granite floor emerges from beneath them.

The old Uliassutai trail

At this point also the old Uliassutai trail crosses the valley, and here we pitched camp for a few days. For the first time in a month the Expedition was in touch with the main transportation arteries of the Gobi region, and we had the good fortune to see some of the great caravans that carry trade from China to the most distant portions of Mongolia. It is not a rare sight, of course, but, for all that, a most impressive one each time it is witnessed, to see these silent caravans swinging along an old trail. They carry merchandise of surprising value, and represent the chief means of intercourse which this interior country has with the outside world. We saw a caravan of two hundred camels, bearing tea, silk and cotton cloth, glide off into the fading glow of sunset, in train almost a mile long. Sixteen unarmed men were the only guards and guides for nearly two thousand miles through the Gobi to Uliassutai and Kobdo. One has no more thrilling experience in a desert than is furnished by this phantom-like procession with its tinkling bells, the soft, almost noiseless shuffling of padded feet, and the strangely majestic forms that loom up in the gathering dusk as the caravan starts on its nightly journey. One can never forget the strange sight, and one conceives a lasting respect for the strong, patient, ungainly beast of burden that lends such dignity to commercial adventure and such picturesqueness to these silent, endless stretches of hopeless sand and jagged rock.

In exploring near the camp it was soon discovered that the recent sediments observed along the valley to this point disappear within a short distance; and although the same surface levels are maintained and the relief

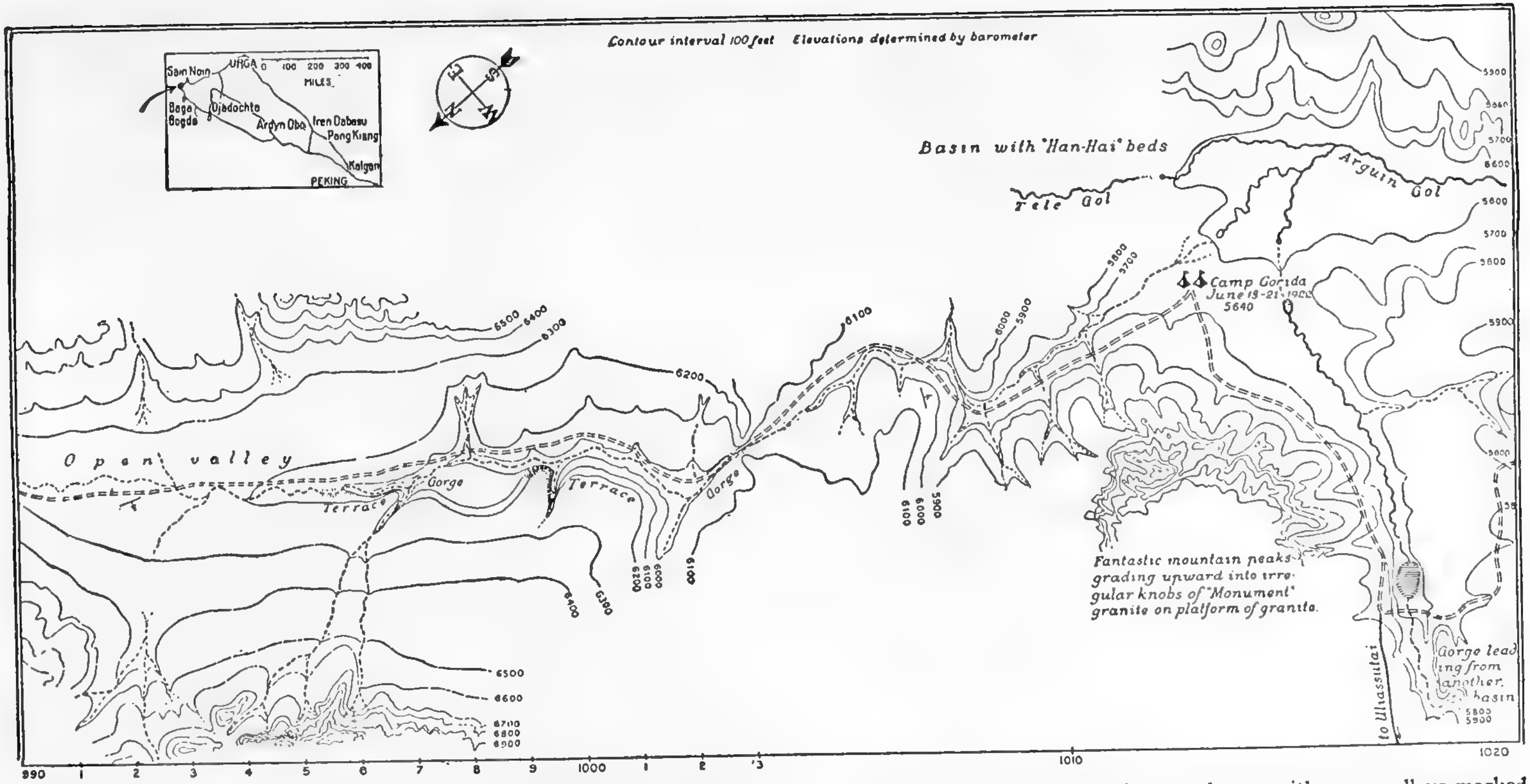


FIGURE 58.—Sketch map of the route covered by figure 57. The southern slopes of the Khangai Mountains are shown, with open valleys marked by broad terraces. The "fantastic mountains" east of Camp Gorida are illustrated in figure 59.

is regular enough to suggest the same simple understructure, actually within a mile of the camp, ledges of granite and gneiss outcrop and the stream carves its trench across these ancient rocks. The valley is an oasis-like spot, with a multitude of springs, whose streams divide and subdivide and swing across the flat bottom-lands in a most delightful way. Good pasturage for caravans and abundant water make it a convenient place to stop for a day's rest; but

FIGURE 59.—The ragged mountains of Gorida. The rock is granite cut by numerous dikes, and weathers into fantastic, bare, and rugged "monument" shapes.

it does not offer much promise of geological discovery. There is nothing unusual in the region, except the small display of later sediments that we have just been over, and these seem to be barren. It was decided, therefore, to continue southward toward the Baga Bogdo mountain mass, which could be faintly seen in the distance, seventy-five or one hundred miles away.

OLD ULIASSUTAI TRAIL TO MT. USKUK

From the jagged granite crags near the last camp we looked across a great basin extending far to the south toward the Altai Mountains, and saw in the distance two very prominent mountain ranges. The nearer one, called Uskuk, is clearly of moderate elevation though striking enough in its relief as viewed across the intervening distance of thirty or forty miles. Far beyond Uskuk, towering to what seemed an enormous height, loomed a magnificent range. The snow which capped the crest descended through a network of valleys in a delicate, lacy pattern, ending in a fringe of dangling sabre-points. At this great distance, through the matchlessly clear air, the snow reflected its daintiest blue where the light fell, deepening a little in the shadows. The base of the mountain was almost invisible, so that the infinitely delicate snow-tracery seemed to grow from the air, reaching upward into gleaming peaks, less of the earth than of the skies. Some touch of primitive poetry in the Mongols seems to respond to the thrill of this ethereal beauty, for they have named many of their greatest mountains after their God. The range before us was the Baga Bogdo, the Lesser Buddha, while, far to the west of it, a mere outline in the sky, stood the Greater Buddha, Ikhe Bogdo of the Altais.

We were prepared to believe from previous observations during the summer's work that, in this great basin which stretched out between the Uliassutai trail and the Uskuk range, and again between that mountain and the Baga Bogdo, we should find larger deposits of the later sediments, and that these might give better returns than had been found elsewhere. Certainly the promise in every geological respect seemed better toward the south than in any other direction, so our course was taken straight toward Mt. Uskuk, which we later learned was the chief peak of this range.

The first step was a detour to reach the platform, or erosion plane, beveling the crystalline rocks already noted as forming the surface along the Uliassutai trail. From this point southward for many miles there are no covering sediments; the rock is almost bare, but is cut by erosion to a fairly uniform level which must represent some kind of planation (Fig. 60). What particular explanation it may have is quite another question, but no such uniformity of level, across such a variety of formations, could be developed except by base-leveling of some kind. (See Chapter XIX.)

Granites cut by multitudes of dikes and pegmatite veins, and carrying more or less completely digested xenoliths of older rocks, were crossed for at least twelve miles. They undoubtedly represent the granite bathylith, which varies somewhat from the average type, to be sure, for in this locality the granite has the most striking development of pegmatitic facies thus far noted. It is possible that here the magma was capable of more mineralizing effect on the original enclosing rock than is produced elsewhere, but no metallic mineral exhibits were seen.

But about ten miles south of the Uliassutai trail, there is a striking change; the granite is replaced abruptly, at mile 1,027, by older gneisses, schists, and interbedded limestones dipping steeply southward (Fig. 61). Whether the change which comes so abruptly is due to a fault, we do not know, but this seems probable as we did not see a transition or other form of contact. It is equally possible, of course, that the granite bathylith has invaded higher levels in the country just crossed and that the traverse now enters upon an undestroyed portion of the roof. One of the most striking constituents of this ground is crystalline limestone, which appears in thin layers, associated intimately with gneisses and schists. Most of it is bluish to white in color, thoroughly crystalline, and still preserves some bedding structure. There is a great variety of other rocks, but they all fall within the general groups of gneisses and schists, and they are all heavily injected by igneous material. Some of these igneous portions are old enough to be affected by the deforma-

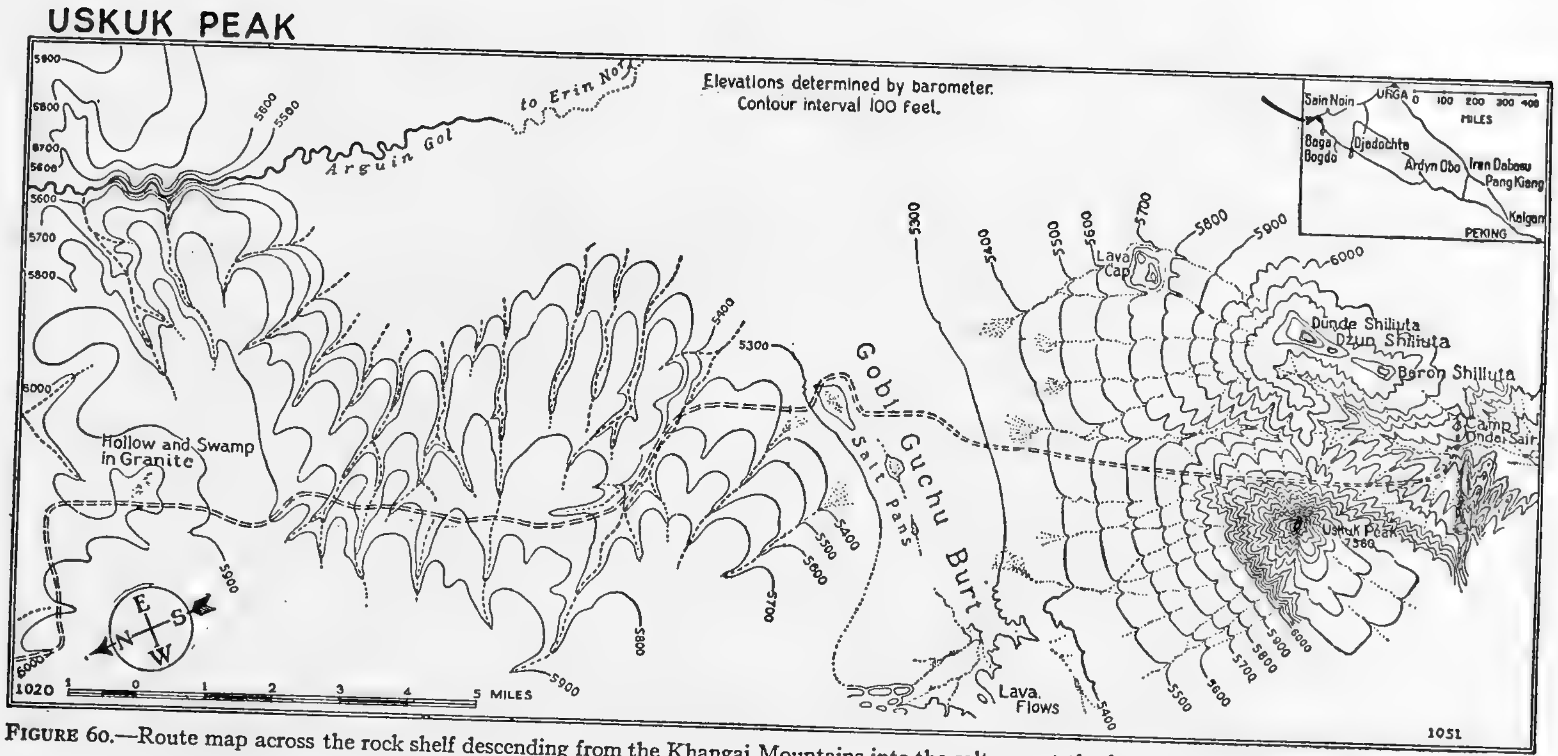


FIGURE 60.—Route map across the rock shelf descending from the Khangai Mountains into the salt pan at the foot of Mount Uskuk. (See Plate XVIIB.)

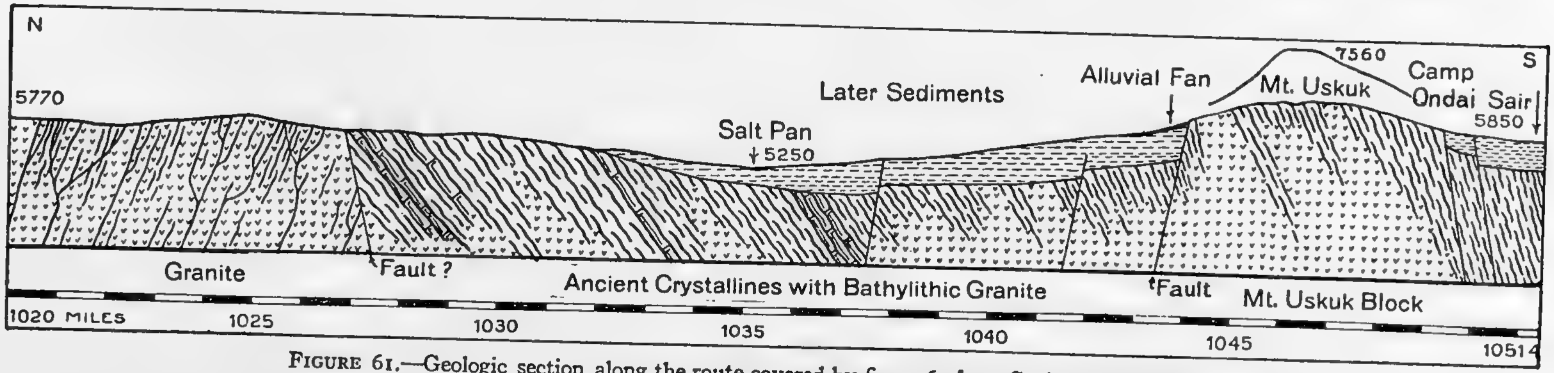


FIGURE 61.—Geologic section along the route covered by figure 60 from Gorida to Mount Uskuk.

tion of the series. Their composition ranges from granite to diorite. Much of the ground is covered with disintegration débris of finer material, the character of which is not readily determined in the field. Perhaps they are phyllites or slates; or a younger infolded and much metamorphosed formation, possibly representing the graywacke-slate series.

The gently sloping erosion plane continues over granites, gneisses, schists and limestones, for twenty miles from the Uliassutai trail, and descends into a shallow basin-like depression ten miles or more across. Later sediments form the floor, and the older basement-rocks are completely covered for the rest of the distance to Mount Uskuk. For the most part these sediments are not well enough exposed to secure typical samples or to determine their content. The surface is not the result of deposition, but is strictly an erosion plane, and, instead of being a down-warped segment partly filled with depositional débris, it is an erosion valley cut into a body of sediments which formerly had greater extent and more nearly filled it.

The Saltpan of Guchu Burt

This erosion form is clearly seen near a small saltpan in the very bottom of the valley, where the sediments are exposed in a low scarp, proving that the hollow is not a place of present deposition, but one where for a long time erosion has been the dominant process.

The saltpan is not more than an eighth of a mile long, and was the first we had seen since leaving Iren Dabasu, a thousand miles back along the route. Salt is actively precipitating at the present time, and we had the good fortune to see Mongols gathering it by the bucketful and loading it on camels (Plate XVII, B). The little dry lake has no outlet, but there must have been a time not long ago, when this was simply a portion of a valley through which a stream ran, and there must have been an outlet through which most of the material, now missing, was carried. But the present bottom is a series of undrained hollows, and there is no semblance of a stream course in its minor features. It is evident that something else has modified the form, and the only agency that could have done it is the wind. Here in the basin immediately north of Mount Uskuk, as in many other places, the wind is eroding and modifying in a minor way the sculpture work of former streams. There is thus a superposition of topographies by different successive agencies.

ONDAI SAIR

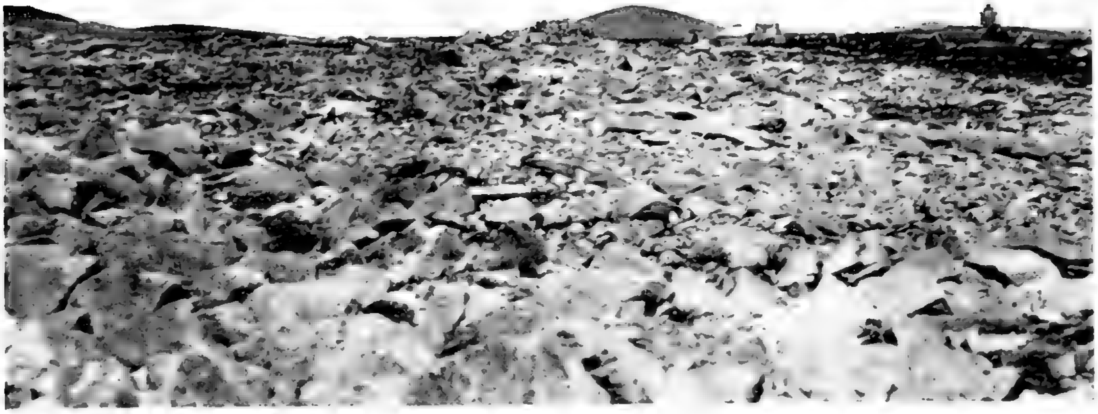
The traverse was continued across the east foot of Mount Uskuk, over a divide into the next basin beyond. This is extremely rough ground, especially on the margin of Mount Uskuk, which stands more than fifteen hundred feet above the salt basin. Only a few miles beyond the peak, the Expedition went into camp near a well at Ondai Sair, which lies in a reëntrant of the Uskuk block on the slopes that lead down toward the basin at the foot of Baga Bogdo. This was Camp Ondai Sair, destined to be for a few weeks an important center of Expeditionary geological activities. A stream course called the Hsanda Gol rises on the slopes of Mount Uskuk and flows southward into the piedmont lowland, where it is lost. Some twelve miles down the Hsanda Gol, is Loh, another spot where extensive explorations were made. Beyond, in the bottom of the basin near the foot of Baga Bogdo, lies Tsagan Nor, a small, shallow salt lake where the central camp was located during the progress of work in this region.

In this manner we entered the Tsagan Nor basin. Only a casual examination was needed to prove that this was a promising geologic and palæontologic field, and it was decided to spend some weeks in an attempt to unravel some of the stratigraphic intricacies of the later sediments. This is the district known as the Mount Uskuk-Tsagan Nor area, where a special local study and a reconnaissance map of nearly seven hundred square miles were made, and the stratigraphic and structural relations were studied in greater detail than at any other place in the Gobi region. Descriptive detail as well as summaries of the results of this work are included in Chapter XIII, in Part III of this volume.

PLATE XVI.

A MONGOL BOY AND HIS FATHER INSPECTING THE CAMP AT SAIN NOIN

PLATE XVII.



A. THE BLOCK STAGE OF DISINTEGRATION IN THE GRANITE AT ARISHAN.

B. GUCHU BURT, A SALT PAN IN THE BASIN NORTH OF USKUK MOUNTAIN.

CHAPTER VIII

THE RETURN JOURNEY FROM TSAGAN NOR TO ARTSA BOGDO

CHOOSING A ROUTE

THE month of July and the first part of August, 1922, were spent in the Tsagan Nor basin, with the headquarters camp pitched on the north side of the lake. By that time it was deemed wise to begin the return journey. The distance to be covered on the way back to Kalgan was estimated to be approximately one thousand miles, and since we expected to travel more or less independently of the main caravan trails, across a country quite unknown to the Expedition and on which very little information could be gathered from the natives, we anticipated that it would take the rest of the good-weather season. If traveling proved to be good it would be possible to stop at several places on the way and make the usual local field studies. On the other hand, if the region proved to be impassable the whole Expedition might be compelled to turn back and seek a different way out. The uncertainties of the trail, therefore, gave some concern, because of the approaching limit of supplies, particularly of gasoline for the motors.

Accordingly, on Sunday morning, August 13, 1922, the whole camp was packed up and the return journey begun. The plan was to travel along the Kweihwating-Kobdo trail, which follows the bottom of the Tsagan Nor basin, skirting the east end of Baga Bogdo, and passing not far from the northerly edge of the Artsa Bogdo range, fifty miles farther to the east. This was known to be a commonly used caravan trail, but its character as a roadway for motors was wholly unknown. Many difficulties were encountered, none of which, fortunately, proved to be insurmountable, and the whole Expedition moved along it without much real hardship, although there were frequent stops for reconnoitering and the finding of passageways across treacherous places or around impassable ground.

On this return journey the same methods were employed by the geological staff as were used on the outbound traverses. A running profile and a geologic cross-section were kept, and a route map was constructed as the

Expedition proceeded. Wherever possible a more detailed study was made. Over part of this return journey, ground was covered very rapidly, and in those places observations were necessarily scattered, leaving much to be desired in the construction of an adequate cross-section. In the belief, however, that such facts as were determinable are more useful in this form than in any other, the running section was continued and has been reproduced in as much detail as the conditions of travel warranted.

Beginning with the summer camp at Tsagan Nor as a zero point, the mileage is counted continuously along the course of the journey, and wherever side trips have been made they are included as extra traverses.

TSAGAN NOR TO THE VOLCANIC CLIFFS

At first the trail runs for miles over the simple, nearly flat-lying, sandy and clayey sediments of the Tsagan Nor basin, of Miocene to Pliocene age (Fig. 62). All of the strata for the first fifteen miles are apparently Miocene; at least, they are closely associated with beds of known Miocene age, as indicated by the summer's fossil collections. Most of the irregularity of bedding and most of the deformation of the beds are exhibited in a north and south section more prominently than in the east and west section along our traverse. The course of the trail for the first fifteen miles was about S. 70° E. and in this section, therefore, the beds have to be represented as lying nearly flat. They appear to rise gradually in the scale until mile 15 is reached, where the strata are notably upwarped. At this point we pass from Miocene strata below to the overlying Pliocene beds, which are prominently exposed in the adjacent Hung Kureh foothills bordering the northern side of Baga Bogdo.

The strata for the most part contain no fossils, and although beds considerably higher are known to be Pliocene and beds below are known to be of Miocene age, it is quite uncertain just where the boundary lies between them. The strata present a regular succession of apparently conformable beds. If there be a break of any kind it was not evident along the trail, or at any place in the district. Doubtless there are gentle overlaps, not only between formations of different age, but within those of a single period or epoch; and some overlaps doubtless occur in this district, where the developing strata must have been affected by the continued Baga Bogdo uplift. The only result noticeable along the trail, however, is a slight warping of the beds so that one traverses the beveled edges of strata that dip very gently. This is especially prominent from mile 13 to mile 18, along the Kobdo trail.

We drive, therefore, not across a plain of deposition, but across shallow basins and very low ridges, over gravel-covered flats and across sand-covered stretches where the surface forms, developed by erosion, suggest the inter-

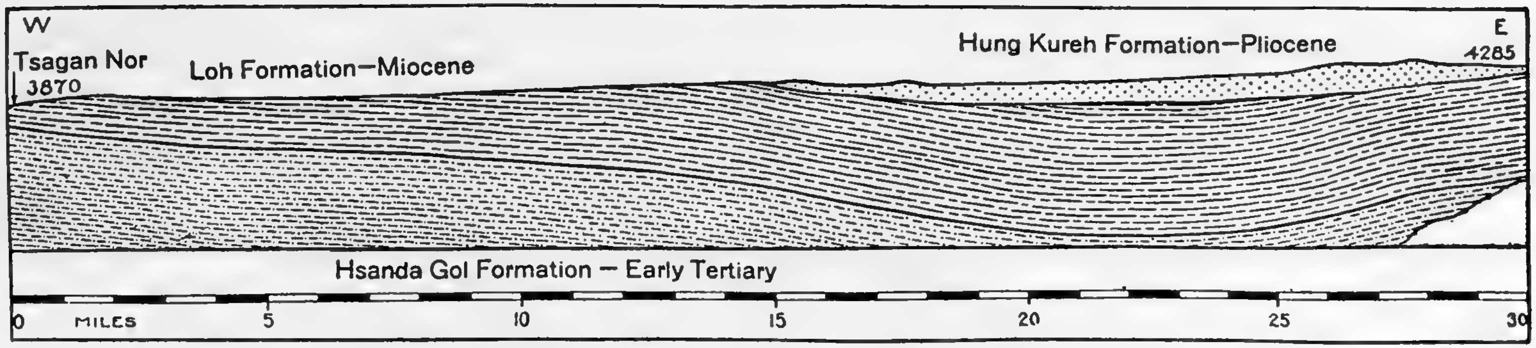


FIGURE 62.—Beginning of the homeward journey from Tsagan Nor. The section runs nearly parallel to the strike of the sediments which dip gently southeastward.

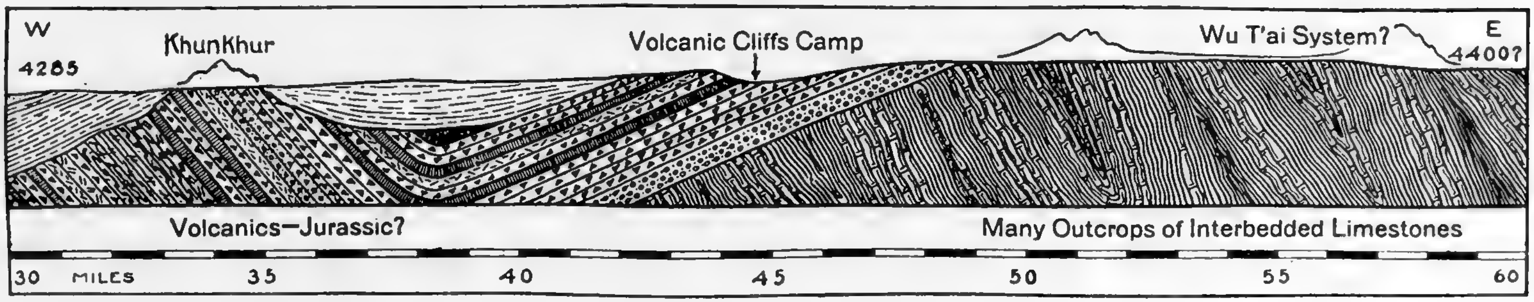


FIGURE 63.—Easterly margin of the Tsagan Nor basin. The stripped oldrock floor emerges through the later sediments. The floor is made up of two widely different members, a younger series of moderately folded lava flows resting upon conglomerates, and an ancient complex series of schists and crystalline limestones composing the Shara Khata Mountains.

pretation just given of the underground structure. Some of these forms are cuesta-like, facing north and south, but so gentle that their significance is readily overlooked. In general, there is a pitch to the eastward, so that as one progresses along the trail one rises in the stratigraphic scale and comes in touch with higher and higher beds.

Desert hollows

At many places along this part of the journey, small, undrained, basin-shaped hollows are seen. They are not related directly to structural deformation, but are the result of erosion. Very often the edges of sandstone and clay-sand beds are fairly well exposed in the sides of the hollow. It is unusual, of course, to find such a depression surrounded by very high enclosing walls, but it is not unusual at all to find a hollow that is noticeably lower than any possible outlet. In no case were we able to detect deformation that would account for the form; and to our best belief the only defensible theory of origin is that of deflation. Apparently the wind has gouged out these places and has carried away the fine sands and the still finer silts of the original beds.

There seems to be no escape from the conclusion that this is a comparatively common type of desert erosion. It apparently starts at some point of easy attack on one of the formations, perhaps because of peculiar textural quality, and when it has once begun, the process seems to be capable of continuing and in some cases accomplishes a surprising amount of excavation. The bare surfaces of exposed ledges indicate clearly that the process is continuing now, and that these hollows are being enlarged by removal rather than being filled by deposition. Moisture is found at the bottom of some of the hollows, suggesting that downward erosion by the wind is limited by reaching the water-table. At any rate, there must be some very regular dependence or control which limits the depth of excavation; and it appears that when this is once attained, enlargement proceeds laterally, almost as lateral planation does with a river (see Chapter XIX).

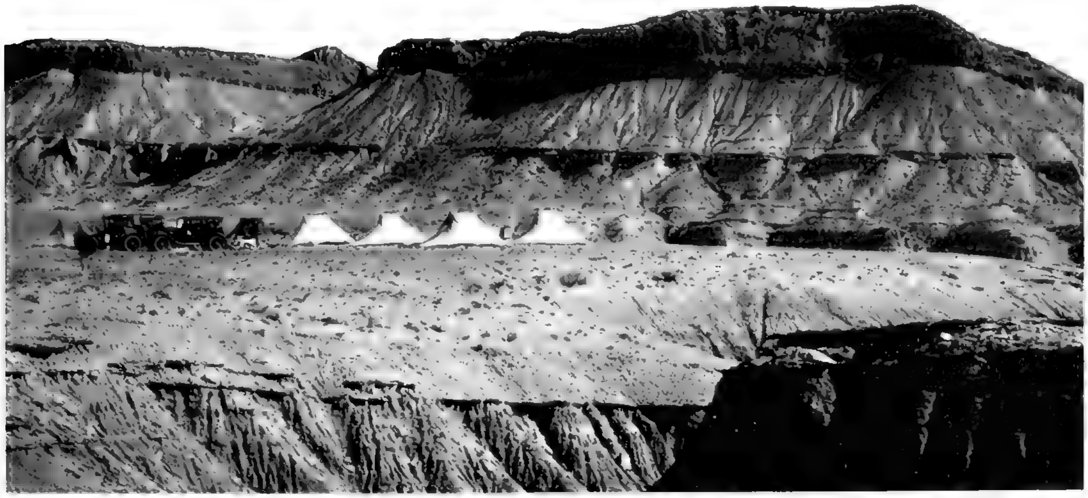
On the margins of these hollows a good deal of drifting sand was encountered, making it difficult to follow the trail through the depressions. Upland traveling is, on the whole, reasonably safe, but difficult going and treacherous ground are not at all uncommon in hollows of this kind, especially in the broader ones.

For the next fifteen miles, to mile 30, it is judged that the strata are probably Pliocene—at least they are a continuation of the uppermost beds of the ground crossed by the trail. At first the dips are easterly; then they begin to change, until between miles 25 and 30 they are reversed, and the bedding dips westerly or backward along the course. Transverse to this direction, on a line running from north to south, the beds also show warping; and the geo-

PLATE XVIII.

A. TSAGAN NOR.

The sand dune belt of Tsagan Nor, with Hung Kureh in the middle distance and Baga Bogdo in the background. (See Plates IV and XXX for location.)



B. EASTERN END OF THE LAVA-CAPPED MESA AT OSHIH.

(Compare Fig. 118.)

logic structure along that line is indicated in generalized form at mile 25 (Fig. 62).

Some of the waters that drain from the northern slope of Baga Bogdo form permanent or intermittent streams with occasional pond-like enlargements. Along this part of the route we crossed the dry valleys of many such distributaries, but between miles 18 and 23 we forded several small running streams with much difficulty, building narrow dams of turf-sods across them for the wheels of the motor cars. The water-table lies close to the surface, just as was the case for miles this side of Tsagan Nor, and the cars were in almost constant danger of miring.

There is a long, narrow, scimitar-shaped area of dune-sands lying between the trail and the margin of Baga Bogdo, several miles to the south (Plate XVIII, A). The dunes are most extensively developed just south of Tsagan Nor, where they form a belt probably fifty miles in length, and where individual dunes are 50 to 300 feet high. It was quite impossible for the Expeditionary outfit to cross the dunes. Indeed, the whole belt bordering the southern trail for many miles is so heavily clogged with drifting sands that it is quite impassable for motor cars. But the caravan trail farthest from the mountain is comparatively good, and even where it traverses ground hopelessly covered with drifting sands, the trail itself can be followed with comparative ease and safety. On either hand the heaving waste of dunes stands back from the trail as the waves of the Red Sea hung back along the flanks of the Israelites' march out of Egypt. Along the trail itself, the feet of countless caravans have stirred up the sand and trampled out the plants that grow on the dunes, so that the fine sand has been blown away by the wind. Only the heavier particles remain, forming a firm pavement. This peculiar condition was found at many other places on the return journey, and for much longer distances than had been encountered before. Sometimes for many miles at a stretch the only possible progress was made by keeping cautiously in the major trail. Even then the traveling was difficult indeed, and sometimes looked quite hopeless. However, the worst of this kind of ground lies to the east of the Tsagan Nor basin and was yet to be encountered by the Expedition.

In this district a surface-water supply was more common than elsewhere in central Mongolia. Drainage from the near-by mountains finds its way out into the basin, and the water does not always sink completely into the sands. Here and there streams actually flow for miles across the plain, and constitute one of the real difficulties of the trail. Uljitundur Gol, a stream at mile 30, is typical of these distributaries coming from the mountain side. It would doubtless be possible to use this water for irrigation, but as far as observed by the Expedition, no such use is being made of it in any part of the region.

At mile 28 the course of a large valley could be distinguished plainly, leading away from the mountain toward the northeast. It must have been made by stream erosion where now no competent stream exists. This is another of the numerous evidences of changed climatic conditions. With the present rainfall it would be impossible to carve a valley of such magnitude. Therefore, the presence of these forms, demanding different conditions for their sculpturing, lends strong argument for a different climate in former times. There must have been more water, and there must have been greater streams—for valleys were carved out which are now slowly filling or are kept cleaned out by the work of the wind, which helps to remove the new deposits.

Because of the westward dip of the strata, it is judged that the beds coming to the surface between mile 30 and mile 33 are probably Miocene (Fig. 63). A little distance away, at the side of the trail, volcanic rocks of the typical chip-fragment type, apparently like those that have elsewhere been found closely associated with the Jurassic strata, project through the surrounding, simpler, Tertiary beds. The trail passes over the very edge of a small knob which extends some distance north of the trail and appears to be surrounded by sediments. It is a ridge of the oldrock floor, laid bare by the removal of the sediments which once covered it.

No fossils were seen in any of this ground. General petrographic and structural quality are the only criteria present for use in correlation. Perhaps the strata are still older than Tertiary, but they are simple in their relations and evidently are unconformably placed on the volcanics.

The first volcanic outcrop was found at miles 34–35, and then the trail passes for several miles over sediments again, but farther on it winds through a low ridge of rugged hills, made up wholly of igneous rock associated with fragmental beds of red and yellow sands. The igneous rocks are chiefly lava flows, including rhyolites, felsites, and basalts. In addition, there are pyroclastics, but these are not so common as are the normal flows. Passing through this ridge and down into a small stream valley at mile 45, the day's traverse was ended, and the Camp of the Volcanic Cliffs was pitched on the banks of a stream of water which was usable, though somewhat charged with mineral matter. Up to this ridge the country had been smooth and open, chiefly of the simple sedimentary basin type. Here we entered a section of ruggedly dissected older rocks. The volcanics may be of Jurassic age, but of that there is no certainty.

VOLCANIC CLIFFS TO ARTSA BOGDO

The traverse was continued on the following day over the trail leading rather abruptly out of this valley to an elevation 400 feet higher. The volcanics continue for a few miles and then give way at miles 47–48 to conglomerates, which have the general appearance of the Jurassic strata. After climbing out of the valley to the plain again at mile 49, another change in the geology was observed. The conglomerates gave way to the much older and more complicated formations of the Shara Khata hills. Limestones standing on edge, associated with schists and quartzites, form the floor for a good many miles. Evidently this is a part of the pre-Cambrian, such as had been encountered at many other places where the most ancient floor is exposed.

In this territory the traveling is good, the trail is well marked and sound, and there is little drifting sand. At either side of the trail craggy remnants of these ancient rocks stand up 100 or 300 feet in height, and the trail passes through the gaps and saddles between them. There is a cover of disintegration soil, so that outcrops are not very numerous, but the floor can be seen at intervals frequent enough to determine beyond question that the whole of it is of this complex series, of which crystalline limestones form the most characteristic member (Specimen 459, A.M. 10148). The floor rocks are all folded and faulted, and extensively modified by metamorphism of various sorts. The strike of the beds varies considerably, and the dip is still more variable. At mile 51 the strike is southeast; at mile 56 the strike is east and west and the dip is north; at mile 56.5 the strike is S. 80° E. and the dip is south; at mile 57 the strike is north and south, with the beds standing almost vertically.

The complex ancient series continues without interruption to mile 60 or mile 61 (Fig. 64). In the vicinity of miles 61–62, volcanic rocks of felsitic and rhyolitic type, similar to those that we have usually credited to Jurassic outbreaks, are encountered on the edge of an open plain which extends thence eastward for many miles. Certainly a younger series comes in at this place rather abruptly, just as it did on the western side of the Shara Khata hills, and includes types of rock similar to some of those seen at the opposite side in the vicinity of Camp Volcanic Cliffs. The open plain, which begins at mile 63, is covered; nevertheless it is certainly made up of simple sedimentary strata lying nearly flat and probably corresponding to some of the strata seen many miles farther west in the Tsagan Nor basin. Their age could not be determined. They are thickly covered with sand, and the trail is gravelly. At mile 68, however, a flow of basalt is intercalated with the strata.

At mile 69, the course, which to this point for 69 miles has been easterly, was broken, and the Expedition turned directly southward, toward the foot of Artsa Bogdo. The new course led over simple strata and in a short distance began to climb up over the superposed alluvial fan carried out from the edge of the mountain. From this point to the camp, which was pitched at mile 80, ten miles south of the trail, the ground rises more than 1,200 feet.

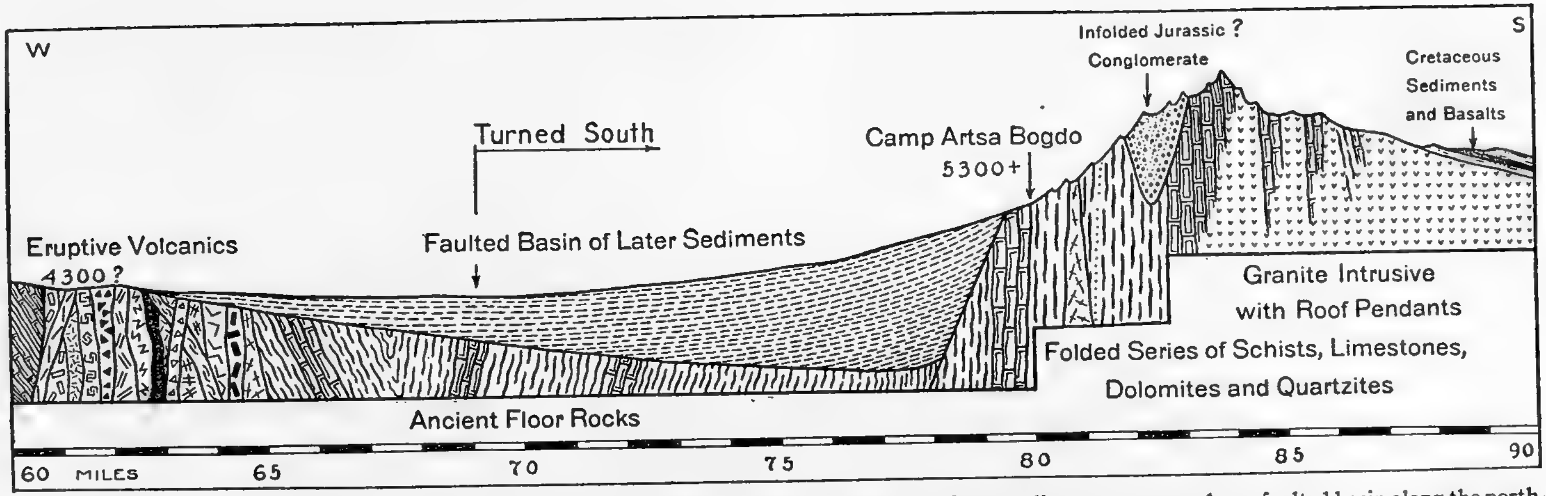


FIGURE 64.—A side traverse from the Kweihwating trail, southward across Artsa Bogdo. Later sediments occupy a down-faulted basin along the northern base of the range, and are steeply upturned along the fault zone. A continuation of the same series, but less deformed, rests upon the southern slopes. The mountain is of simple block form and is an uplifted portion of the oldrock floor.

Camp was pitched here on a sloping shelf of ground, at the very edge of the steep front of Artsa Bogdo. With good water near by, the location is admirable for a camp. It is within easy reach of the rugged Artsa Bogdo mountain group, and within striking distance of the sedimentary basins of the plain. This camp, therefore, became another expeditionary center, and side traverses, occupying the next two weeks, were made by the several divisions of the Expedition.

NORTH MARGIN OF ARTSA BOGDO

A day was spent in examining the margin of the Artsa Bogdo uplift. On the way to camp we had noted a large mesa south of the road, near the foot of the range. Its cap of black basalt, and the white and red sediments showing here and there on its scarred flanks, make a rare color composition. In the lowland between the mesa and the road, extensive red-beds are exposed. Our first side traverse was to the west, to study the mesa and the adjacent red-beds. For many miles alluvial fans cover the underground structure. At a distance of 13 miles west of camp, however, ancient limestone ledges form outcrops very similar to those along the trail farther north. From this point on, we encountered limestone carved into rounded knolls which fall into a general uniform level, constituting a platform above which the craggy mountains stand abruptly. This is either the original erosion floor on which the sediments of later age were laid down, or a still younger planation product. Whatever the origin, it is now entirely bare for many miles.

Beyond the outcrop of ancient, folded limestone, at a distance of 15 to 16 miles, a much younger series of beds was found, dipping gently westward and consisting chiefly of clays and sands. Interbedded with them are thin limestone layers, which carry abundant plant remains of a cone- or tube-shaped form, which have been coated with lime carbonate and then partly replaced by colloidal silica. The structural relations suggest that the limestone is essentially an ancient, calcareous tufa formed about plant-stalks and later affected by silica-bearing waters. In the field we judged these beds to be of Cretaceous age, and this inference seems to be supported by such additional facts as are now available.

Simpler strata, belonging to the beds that continue to the mesa, come in next, and with them are associated amygdaloidal basalts which on weathering furnish great quantities of agate and chalcedony pellets.

At the white-cliffed mesa, later sediments, capped with lava, rest upon the gently sloping erosion plane. It is a large mesa, standing well out in the valley, with a series of contiguous outliers. It owes its preservation to a basalt cap which protects it from erosion. Beneath is a series of sandy, clayey and nodular, limy beds. Lava blocks have slumped down over the slopes so that few exposures can be seen. It is clear, however, that the basalt, which is very vesicular, belongs on top. No fossils were found, although diligent search was made in the hour available. The age, therefore, is wholly unknown; but the general aspect is like that of some of the Tertiary beds, especially those of the Hsanda Gol in the Tsagan Nör basin, where unconsolidated sediments are associated with flat-lying lava beds.

Picture writings

On some of the basalt blocks on the white-cliffed mesa, we noted a striking display of prehistoric pictures. One group of these, found on a large, flat fragment, carries the following: two men, one with bow and arrow, several animals, one of which was probably intended to represent a horse, another a reindeer, another possibly a moose, while still another is perhaps a fox (Fig. 159, page 394). None of these animals, except the fox and the horse, is to be seen within several hundred miles of this region at the present time, yet it must be that the artist was familiar with them. Either he belonged to a tribe which came from a region where these animals were native, or else the region itself was occupied in his time by such animals. It is entirely reasonable to believe that the latter is the explanation, and that the artist pictured animals living in his vicinity. This interpretation would mean that the people who made these drawings were not of the Mongol race, and that the climate was other than it is now.

Upon completion of the inspection at the white-cliffed mesa, we turned northwestward across the depression, toward the Kobdo trail, which lay a few miles farther to the north. In making this traverse, beds of considerable thickness and of simple structural condition were crossed. At one point a small development of later conglomerate and sandstone caps a ridge, indicating that, subsequent to deep erosion of the underlying beds, sediments were deposited above the break. These have again been attacked by erosion and almost completely destroyed. The conglomerate carries cobbles of the same basalt as that seen on the mesa, and it must, therefore, be younger than the mesa-cap basalt. Possibly it is Pleistocene. While we made no important finds in any of these strata, it is a district which might well repay additional inspection.

While the Expedition camped at Artsa Bogdo, Mr. Granger made a side trip to the stratified red-beds of Oshih (Ashile), which could be seen in the distance to the north. The geological division, after making a reconnaissance of the Artsa Bogdo block and its margin, took supplies for a ten-day journey, crossed the mountains and the adjacent basin beyond, and finally reached the Gurbun Saikhan, the easternmost of the great uplifted blocks of the Altai mountain system. The observations of these side traverses, as well as those of the vicinity, are included in Chapter XV.

CHAPTER IX

FROM ARTSA BOGDO TO SAIR USU

On Friday, September first, the return journey was resumed. The camp of the Expedition at that time was located on the Kweihwating trail, out on the plain ten miles north of Artsa Bogdo. Since the character of the country for the progress of such an expedition was undetermined, and it was not possible to get satisfactory information about it, it was decided to travel eastward on the Kweihwating trail to the vicinity of Ulan Nor, and then try to find a way northward to the Uliassutai-Sair Usu trail. This, we had reason to believe, would furnish safe going and probably could be followed into Kalgan. If the plan proved feasible, the trip could be made in reasonably short time and without overtaxing our remaining supplies, but if for any reason it should be necessary to turn back and retrace our steps, they would be exhausted before the journey could be completed. We had to start with an overload of supplies, because it would not be possible to replenish any of the stock for several hundred miles. On this account the trucks were put to a severer test than usual, and repairs were frequently necessary. These were accomplished, however, with eminent success, through the great skill of Mr. S. Bayard Colgate, Chief of Motor Transport, who succeeded in keeping the whole Expedition together to the very end.

Every stop, for repairs or for other purposes, was seized upon by the geological party to make closer investigation of the geological features of this portion of the itinerary, but despite every effort the return journey was accomplished much too rapidly for efficient work. The remaining 800 miles of the route to Kalgan, which crosses some of the rarest geological formations encountered in the entire Gobi region, must be described for the most part in general terms, accompanied by sketches of structure which are based on a minimum of actual examination. While the simpler portions are reasonably correct, the more difficult ones are necessarily sketchy and suggestive, rather than dependable representations. There is some hesitation, therefore, in presenting a part of this itinerary, and the decision to include it with the other portions is based on the belief that this is the most effective way to present such observations as were made, and to record the interpretative judgment of the Expedition on the geology of this traverse. This is all the more desirable because of the fact that the traverse is very distant from the route followed on entering the Gobi, and because certain new stratigraphic elements come into the geologic column, and because their relation to the major features, both of a physiographic and of a stratigraphic and structural nature, are in this way determined and located. It is felt, therefore, that the minor features and detail may well be sacrificed, or left to supplementary determination at some later time.

ARTSA BOGDO TO DJADOKHTA

For convenience, the return traverse begins again at zero miles (Fig. 65). For the first five miles the sediments of the lowland continue. We consider them to be Cretaceous sediments related to those of Oshih, ten miles north, where an important fossil field had been located. Beyond mile 5, the ancient crystalline rocks of the floor form the surface, having been stripped by the same erosion that dissected the overlying sediments. The relief features, therefore, are not more prominent in this portion than on the sedimentary plain farther back. Ancient gneisses and schists form the floor at first, then are overlaid by blue and white banded limestones which dip toward the north, and which follow a general strike north of east. The floor formations are evidently folded into a series of anticlines and synclines, which are truncated by this plane and newly exposed. In the course of a few miles, alternations of limestones and gneisses or schists were crossed, but the major portion of this formation is crystalline limestone throughout the whole of the distance from miles 7 to 16. Some of the ground, of course, is covered and outcrops are not very prominent, but there is no difficulty in determining the general underground structure. The presence of brecciated zones, some of which are rehealed, clearly indicates that the rocks have been faulted, but no displacements are recorded in the present topography. All of the deformation recorded in the floor rocks has preceded the development of the present surface. The age of the limestones, of course, could not be determined. They represent some ancient pre-Cambrian type,—probably some portion of the Wu T'ai system, which immediately preceded the graywacke series.

At mile 16, new sedimentary strata begin. Probably they do not represent a new basin, but a portion of an ancient filling or cover of this whole area, not yet destroyed by later erosion. The former sedimentary cover has been stripped from a ten-mile stretch, but for the next ten miles sediments are still preserved, although they probably form a comparatively shallow cover. The country is more rolling than one would expect, and the relief is quite as marked as is that of the crystalline floor just traversed. No fossils

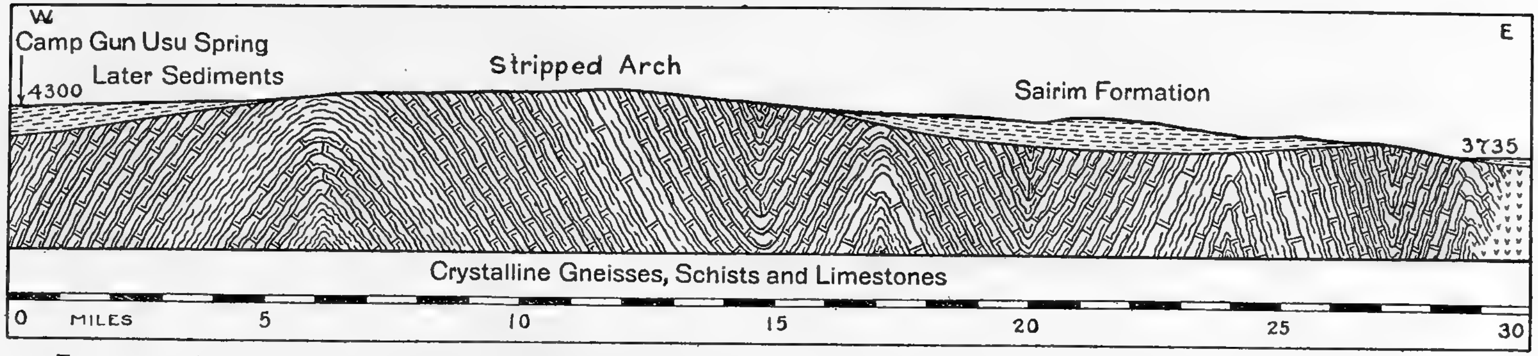


FIGURE 65.—Geologic section along the Kweihwating trail from Gun Usu at the foot of Artsa Bogdo eastward. A closely folded series of ancient crystalline rocks is overlaid by thin remnants of Cretaceous sediments which formerly must have been continuous and of much greater thickness.

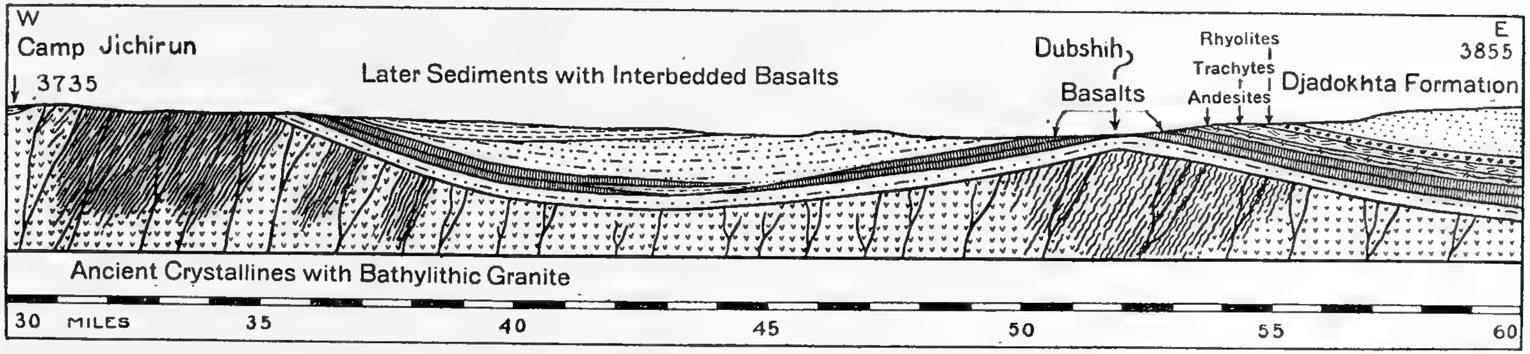


FIGURE 66.—Geologic section entering the Djadokhta basin from the west. A lower series of conglomerates with volcanic flows and tuffs, especially well-developed at Dubshih, is succeeded by the red sands of the Djadokhta formation.

were found here, but in general appearance the rocks are similar to the Cretaceous beds farther to the west. Though there is loose gravel and sand along the dry stream channels, most of the trail passes over bare bedrock, whether the rock be the nearly level sediments or complex folded crystallines. The general underground structure could be determined beyond question, but in a traverse covered so rapidly it is not possible to fix the age or work out minor detail.

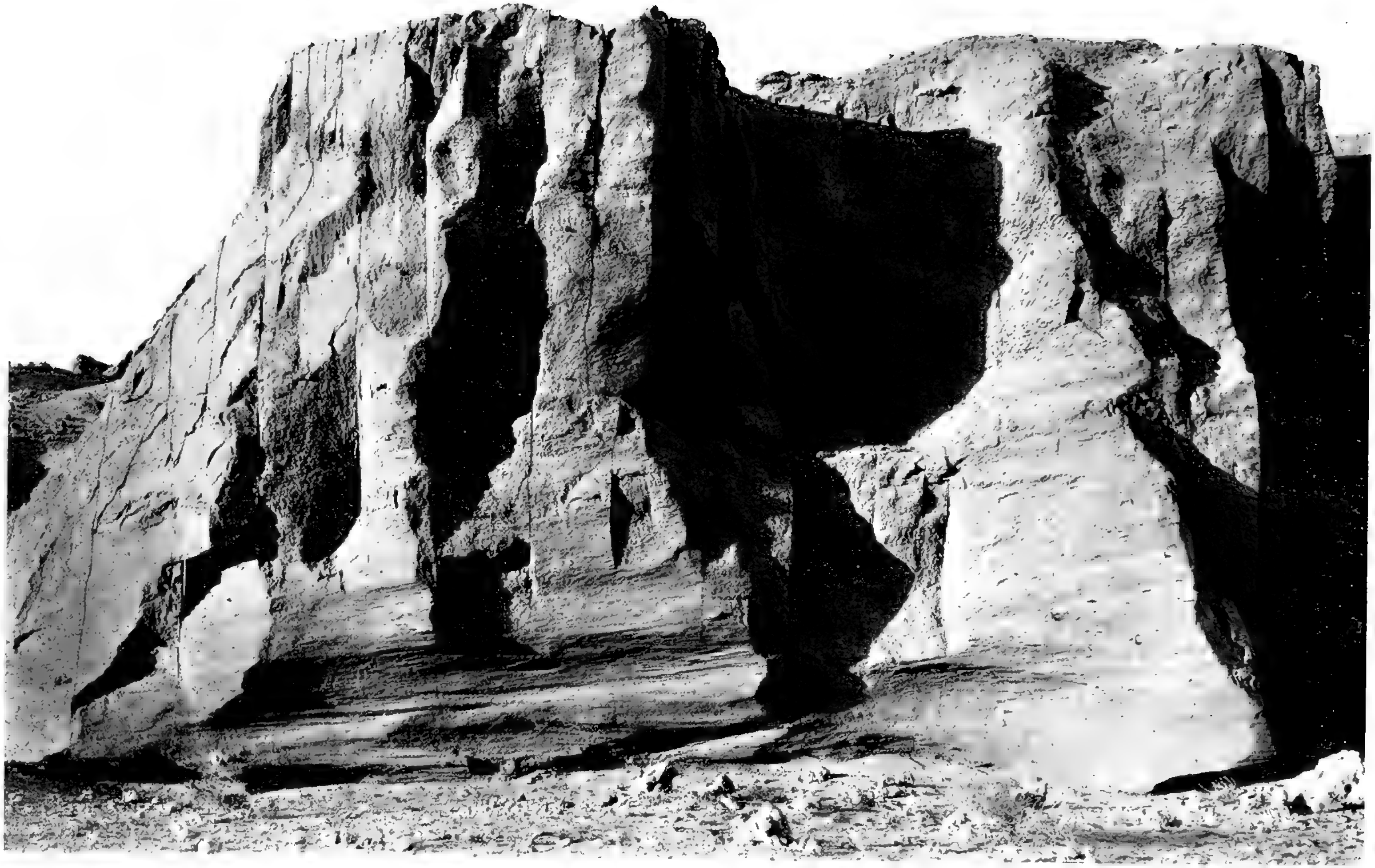
At mile 26, the limestones of the ancient floor are at the surface again, and for a short distance the sediments have been stripped off. The limestones form a small arch here, with strata lying nearly flat, but dipping first to the south and then to the north, passing beneath sediments again at mile 29. This patch is small,—not more than a mile in extent,—and then, at mile 30, granites come to the surface with the usual accompanying dikes and inclusions of country rock, exhibiting all the features of the bathylithic granite described in many other places.

The granite at mile 31 is very coarse-grained, massive in structure and without internal deformation (Fig. 66). It cuts through rocks belonging to the graywacke series and includes xenoliths of this formation. This content increases somewhat regularly, and becomes much more pronounced as the traverse continues toward the southeast along the trail.

At mile 33, the rock is chiefly gneiss and schist with dikes (Specimens 549, 550, 551, A. M. 10238, 10239, 10240). The variety included in the stretch from miles 30 to 35, presents some difficulty in formational classification. That it is a part of the roof material invaded by granite is clear enough, but how much of it belongs to the graywacke series and how much to older formations is not so clear. Apparently the graywacke content is not large, and the stretch as a whole probably represents older formations.

At mile 35, we reached the edge of a new basin, beginning with flows of basalt which dip gently toward the southeast. Above the basalt lie reddish sediments forming a smooth plain which with slight undulations extends for many miles. The age of the sediments at this place could not be determined, but their relation to similar sediments, found a little farther on at Djadokhta, is such as to lead one to believe that they are essentially the same—probably of Cretaceous age, and a lower part of the Djadokhta series. These sediments continue from mile 36 to mile 48, where the basalt flows come to the surface again, this time dipping gently westward into the basin. At mile 45, we crossed a broad valley called Dubshih, in which we encountered standing water and some bad ground. Basalt flows and other igneous materials form the surface then for five miles, and, although the minor structure is not worked out in detail, they apparently form a gentle anticlinal arch and beyond mile 53 dip under again toward the southeast.

PLATE XIX.



WIND-SCOURED CLIFFS AT DJADOKHTA.

The massive, fine, red Cretaceous sandstones of Djadokhta, channeled by wind blast.

PLATE XX.

A. THE GREAT TEMPLE AND LAMASERY, ONGIN GOL IN SUMU.

The view is taken in the Ongin valley, with low hills of the oldrock margin of the sediment basin in the background.

B. A NEST OF DINOSAUR EGGS IN THE RED CRETACEOUS SANDSTONE AT DJADOKHTA.

In this stretch, near mile 53, we crossed some very treacherous ground, for the water-table is near the surface, and the ground is miry and very difficult to get through with the kind of equipment used by the Expedition. At mile 54, rhyolite flows and andesites, with bombs and ash beds, lie above the basalts, and are in turn overlaid by reddish sediments, chiefly sandstones, which continue to the red cliff badlands of Djadokhta (Fig. 67, Plates I and XIX).

The Flaming Cliffs of Djadokhta

The country is smooth and the trail is firm and easy to follow, but since we had reached a point somewhat to the east of Ulan Nor and this was as far east on this trail as we desired to go, we sought an opportunity to turn northward across country. Every effort was made to find such a trail, and inquiry was made of the few natives who were seen. At a point near mile 65, the leaders halted, and while Mr. Andrews sought information at a nearby yurt, Mr. Shackelford inspected the red-beds exposed in the adjacent escarpment, a few hundred yards north of the trail. His first specimen was a nearly perfect skull of the rare dinosaur later named *Protoceratops andrewsi*.

The importance of the locality was at once appreciated; so, in spite of the wish to push forward, camp was pitched a short distance beyond, at mile 65.5, and the rest of the day was given to search of the cliffs and talus slopes of the locality. In the two hours left for this purpose a large number of fragments were recovered, forms which were recognized as new. We appreciated that it would not be advisable to spend the time necessary to investigate this ground thoroughly, so it was marked as one of the fields to be exploited more carefully in the following season. This additional work was done in the season of 1923, and the locality yielded some seventy more or less complete skulls and a dozen skeletons as well as the dinosaur eggs. The first year a small egg was found but not reported—because the full significance was not appreciated at that time. The second season, however, when more than twenty others were unearthed, some of which were in nests with associations that proved them to be dinosaur eggs, the importance of the discovery was comprehended, and the find received the attention that it deserved (Plate XX, B).

The rock is a red sandstone of very uniform grain and comparatively simple structure. The grains are exquisitely graded, so that when the stone is weathered, it yields a sand that will run like the sand in an hour glass. There is virtually no admixed clay, and separate beds of clay are few, occurring chiefly as channel fillings. Many of the sandstone beds contain myriads of small limy concretions, some of them being traceable for as much as a mile. In places the sandstones appear massive and structureless, forming sheer vertical walls as much as forty feet high, in which neither bedding nor color-banding is seen; yet these massive layers pass laterally into well-bedded deposits. Cross-bedding, apparently of æolian type, is developed on a large scale at certain horizons. We believe that the formation is in large part wind-blown, and that this history is the major factor in accomplishing the perfect preservation of the delicate fossils which the Expedition recovered from it. The beds are very faintly disturbed, and show slight arches and saddles, but dip very gently toward the south. To the south of the road, therefore, one might hope to find higher formations. In 1923, a series of clays and clayey sands, bearing a fauna of rare and primitive mammals, was discovered overlying the Djadokhta dinosaur-sands. It was called the Gashato formation, and is believed to be of Paleocene age.

Looking off toward the south we could see that we had reached a point opposite the Gurbun Saikhan, the last of the uplifts of the Altai system. The three sections of this compound group of mountains could readily be made out; the Baron Saikhan on the west, the Dunde Saikhan in the middle, and the Dzun Saikhan to the east. They are essentially ranges of high mountains separated by broad vales, so that they appear as three major units. They form, therefore, a mountain uplift of greater extent and complexity than is usual in the Gobi region, but they have the same fault-block features as the other members of the Altai system,—they are apparently a group of three fault blocks behaving as a larger complex unit.

DJADOKHTA TO ONGIN GOL IN SUMU

The following day the course was turned northward and the traverse was projected across the lowland below the red cliffs (Fig. 67). The lowland, which is an ancient erosion valley, has a steep southerly margin formed by the cliffs of Djadokhta, but on the north side the slopes are more gentle, and it would be easy to climb out of the valley except for the drifting sand, which is more troublesome at several places on this northward traverse than at any other place reached by the Expedition. The difficulty is due in large part to the fact that there is practically no trail, and traveling is always hard in drifting sand, unless there is a good trail to follow.

Later sediments continue almost horizontally, probably dipping slightly to the south—and this partially accounts for the difference in marginal slope in the two sides of the valley. The same general type of sedimentary strata continues for twenty miles. One can see variations in the country, especially to the east, where hills of hard rock are plainly visible; but no other rocks than sediments are encountered on the traverse itself to mile 86, where a sharp flexure in the strata is noticed and there are outbreaks of basalt of irregular form on both sides of the trail (Figs. 67 and 68). Doubtless the volcanic outbreak has come up along a weak zone caused by faulting.

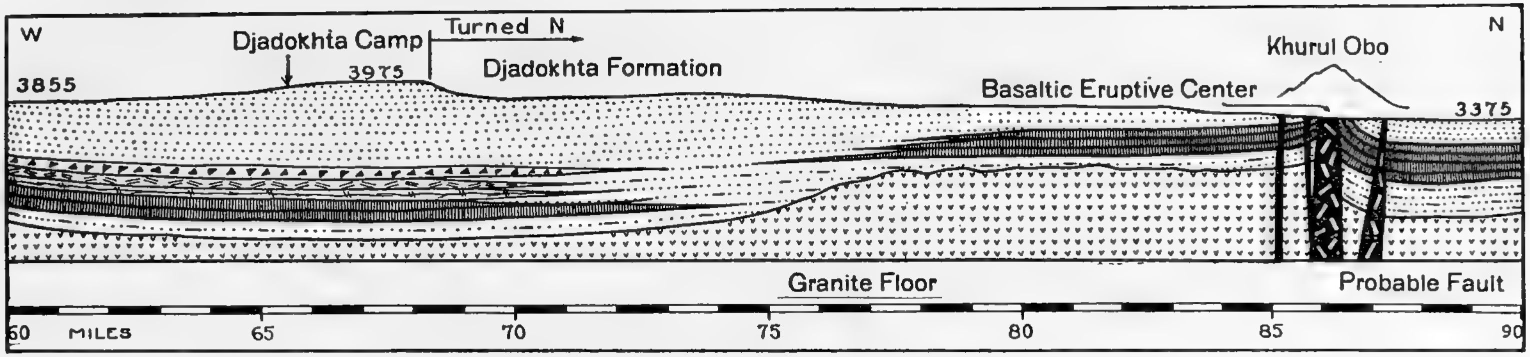


FIGURE 67.—Beginning of the northward traverse from the Kweihwating trail to the Ongin Gol. The scarp at mile 68 marks the chief fossil-bearing locality of the Djadokhta district.

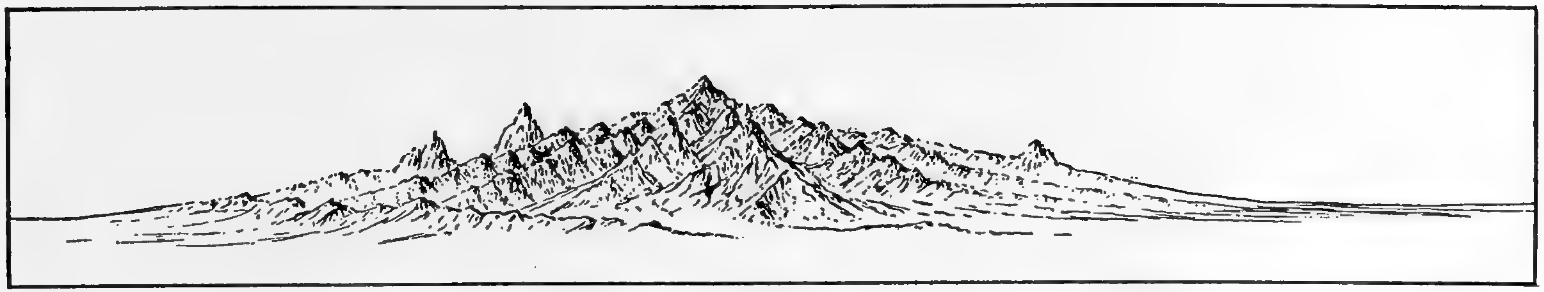


FIGURE 68.—Field sketch of the Khurul Obo, or "Bronze Peak," from the south. It is a volcanic neck, with numerous dikes, one of which is seen in the left foreground.

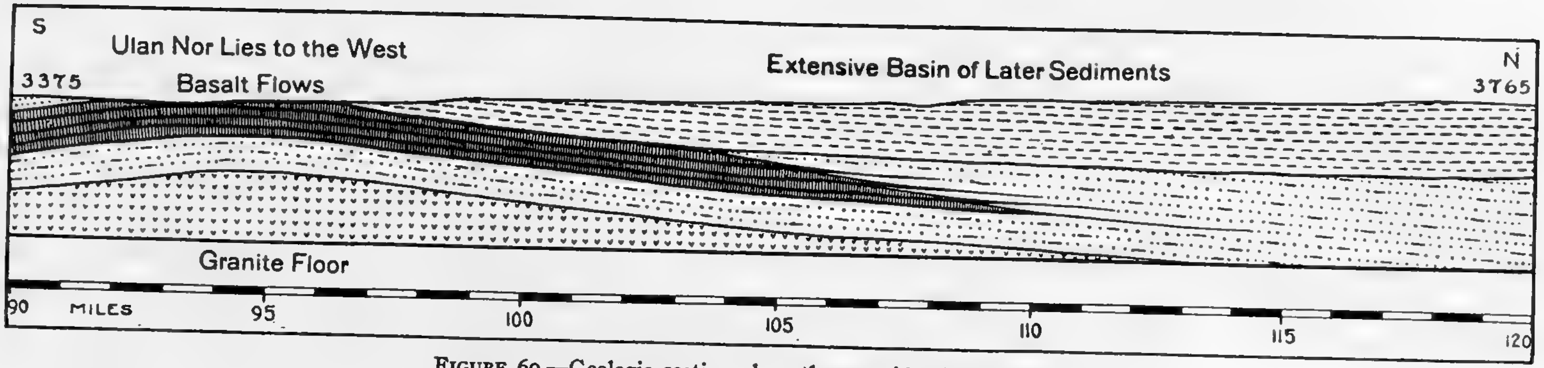


FIGURE 69.—Geologic section along the east side of the Ongin Gol.

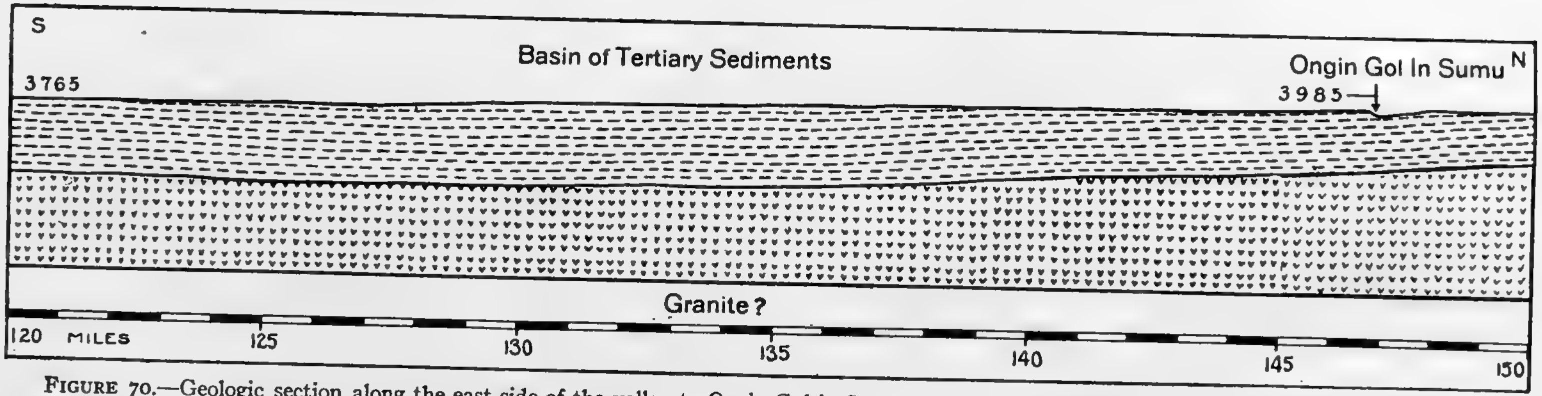


FIGURE 70.—Geologic section along the east side of the valley to Ongin Gol in Sumu. The section traverses one of the finest examples of the Gobi erosion plane. The temple lies in the shallow trench of the Ongin Gol which has almost no lateral tributaries.

Basalts are prominent in the floor from this point for many miles along the trail (Fig. 69). They appear to be interbedded with sediments, and in many places there is a thin wash of silt and sand partially covering them. They are doubtless of the same age as the sediments, probably Cretaceous.

Simple sediments come in again at mile 98 and continue to mile 159 in one of the smoothest, longest-continued level stretches seen anywhere in the Gobi region (Figs. 69, 70, and 71). Throughout the whole distance the difference of relief amounts to a total of less than 550 feet, and for stretches of ten miles together the total variation is not more than one hundred feet, with no local irregularity of more than ten feet. The area is in appearance as level and flat as a floor, but the whole plain rises gently northward at the rate of about ten feet per mile. In the first forty-five miles the greatest local irregularity on the line of the traverse amounted to forty feet. For the first twenty miles considerable trouble with drifting sand was encountered, and in the failure of a definite trail there was delay in finding the best course. The route finally selected lay along the east side of the valley of the Ongin Gol on the very edge of the trench made by the river.

This trench is carved out of the plain to a depth of fifty feet or more. There are almost no side tributaries, so that the margin is smooth and almost unbroken, and traveling on the upland at the edge of the valley is better than elsewhere. After getting somewhat out of the worst belt of drifting sand, the run was made with great speed over one of the smoothest stretches of basin country seen in Mongolia. This upland is a portion of the Gobi erosion plane. Except for the patches of drifting sand, it is covered with gravel—the typical covering of surfaces of this origin. It is essentially an erosion surface undergoing some dissection, and, despite the fact that the Ongin Gol carries sediments from the Khangai Mountains, it is in this region primarily an agent of erosion, and its valley represents the deepest and broadest dissection of the plain (Plate XX, A).

Ongin Gol in Sumu

For many miles the strata are not sufficiently well exposed to determine their precise character, but that they are later sediments of some kind is perfectly evident. Within the edge of the Ongin Gol valley, the Expedition went into camp at mile 147, near the temple and lamasery of "Ongin Gol in Sumu" (Plate XX, A, and Fig. 70). On inquiry there, it was found that the Sair Usu trail lay only a few miles beyond, and that the major uncertainties of the return traverse were already safely past.

This lamasery seems to be one of the better Mongol establishments. There are hundreds of lamas and novitiates, who literally swarmed around the Expedition while their representatives made official calls. Old men, gray-haired, dignified and thoughtful-looking, sat on the ground in groups, doubtless considering the significance of so unexpected a visit. It was an interesting day, and might have been still more so if we could have gained the confidence of these elder priests of Buddha, and entered into the secrets of their thinking. Year after year, their whole lives through, they serve Buddha, some of them doubtless with a singleness of heart quite in keeping with the great master whose teachings they follow. Here and there an older man impressed us with his apparent superiority and look of intellectual acumen.

It would have been especially interesting to talk freely with such a man. One would like to know his view of life, what it is he hopes to accomplish, why he lives this kind of life, quite apart from the opportunities and the activities of his own people—an existence apparently wholly unproductive, unresponsive, unimpressive, unpromising, devoid of almost every element of modern interest and service. He seems a relic of ancient times—times when learning and culture centered in and were preserved by just such priestly communities as this. From our latter-day viewpoint, their life seems that of a day that is past, a clinging to a familiar yesterday, for fear, perhaps, of looking squarely at to-day; yet one should recall that just such apparently unpromising surroundings have furnished some of the great contributions to the religious movements of the world. Most great religions have come from the wilderness or from the desert. Who knows but that there may come again, from quite as hopeless-looking ground, concepts and teachings to shake the foundations of the world? Is the magic of the desert lost? Has God abandoned the quiet of the open wastes to make his revelations in the market place or the pretentious habitations of the arrogant and the scheming babels of the earth? Who knows? And if we do not know, how is it that we so freely condemn these quiet fate-defying priests of Buddha who spend their days in contemplation of the mysteries of life and believe that they are doing the will of God?

ONGIN GOL TO SAIR USU

The lamasery on the Ongin Gol is situated on a terrace within the valley, about thirty feet below the general level of the Gobi erosion plane. The terrace at this point is several hundred yards wide, and is level and dry. It must represent a stage in the Ongin Gol erosion developed during an epoch of climatic conditions somewhat different from those of the present. On leaving this camp the course of the Expedition lay northeastward to the nearest point on the Sair Usu-Uliassutai trail near Tugurik (Fig. 72). For ten miles the same sedimentary strata previously described continue, but the topography is a little more varied than in the plain farther to the south.

At about mile 160, igneous rocks appear at the surface in the form of

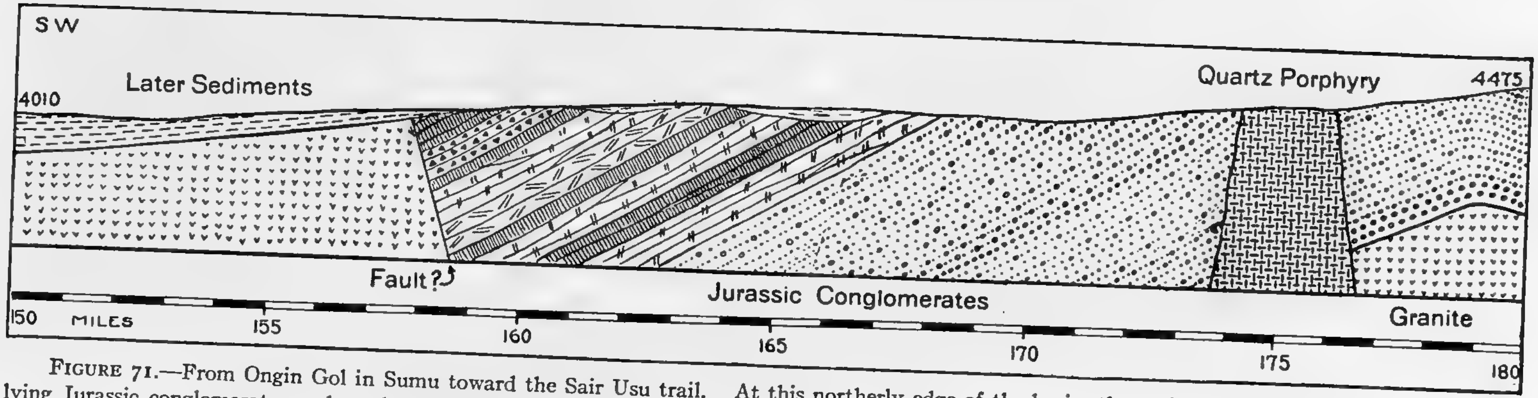


FIGURE 71.—From Ongin Gol in Sumu toward the Sair Usu trail. At this northerly edge of the basin, the sediments are stripped from the underlying Jurassic conglomerates and sandstones which here constitute the oldrock floor.

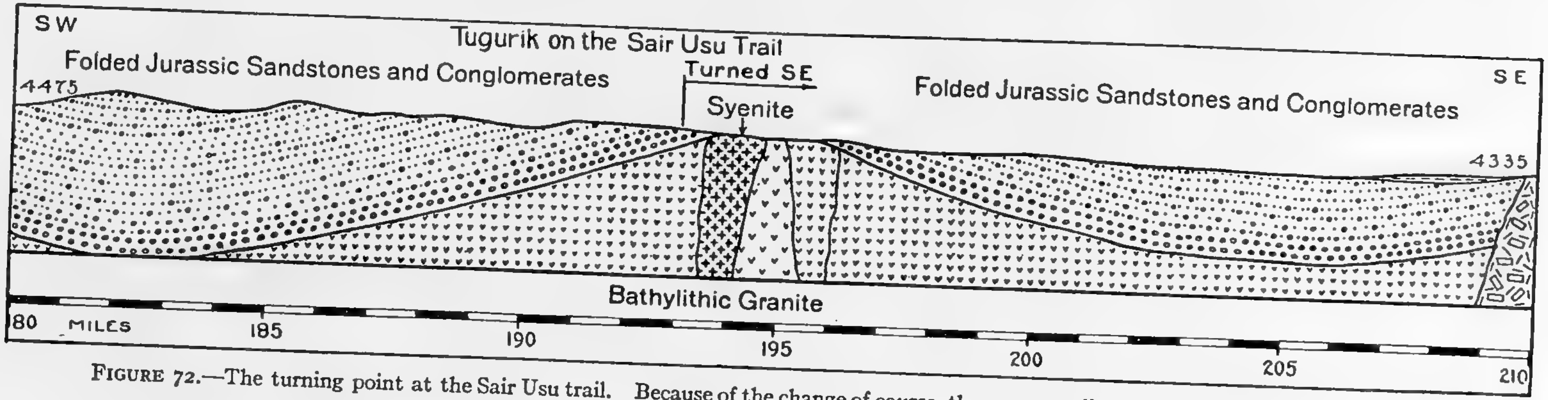


FIGURE 72.—The turning point at the Sair Usu trail. Because of the change of course, the same syncline of Jurassic strata is crossed twice.

low hills and ridges with a still more rugged topography (Fig. 71). The character of the porphyries corresponds precisely with that of porphyries usually found associated with Jurassic strata, and no other strata appear for several miles. From mile 164 to mile 167, the floor is covered with alluvial or sedimentary material in a shallow basin, so that the floor conditions can not be seen clearly. Somewhere beneath this shallow basin, however, the floor rocks change, because typical Jurassic sediments with southerly dip appear just beyond, and continue thence for five or six miles. The dips vary in steepness, but do not change from a southerly direction throughout the distance. From mile 174 to mile 176, porphyries appear again, apparently breaking through the Jurassic sediments, but the conglomerates and sandstones continue from mile 176 to the Sair Usu trail at mile 193. This is one of the finest exhibits of Jurassic sandstones and conglomerates seen anywhere in the Gobi region. The deformation is of simple folded type, as indicated by the changes in dip, and includes two anticlines and a dividing syncline in the last fifteen miles of the traverse.

At the Sair Usu trail the course was changed abruptly toward the southeast, which was the general course through Sair Usu toward Kalgan (Fig. 72). From the Altai Mountains up to this point the traverse lay across a great basin filled with later sediments, with the margin along the Sair Usu trail formed by folded Jurassic strata. At this very spot, where the course was changed, the still more ancient floor comes to the surface where a gentle anticline of Jurassic strata is cut away by erosion. Here there is no question of the gently folded character of the Jurassic strata. The rocks outcropping from beneath the Jurassic are a complex of granite and syenite,—probably some representative of the granite bathylith,—and these massive rocks cut one another in a confused way. This exposed strip is only two miles across, for, at mile 196, the trail reaches Jurassic strata again, dipping this time gently southeastward for several miles, and then sweeping up again to form the other limb of a shallow syncline. Patches of later sediments lie on the truncated Jurassic strata at mile 207 to mile 210, where porphyry breaks through to the surface; beyond this point the Jurassic strata outcrop again for a short distance.

On this journey along the Sair Usu trail, small, shallow basins with alluvial deposits of recent origin are common. It is quite impossible in most cases to determine what is beneath them, but judging from the surroundings they are all very shallow and insignificant, belonging essentially to the present epoch of alluvial wash (Fig. 73). Mile 215 marks the beginning of a long strip of country with the most complex structure seen along the Sair Usu trail (Fig. 74). In the first thirty miles it is essentially a portion of the granite bathylith, cut by many igneous masses of syenite and porphyries, and by exceedingly numerous small dikes of great variety. The separate field units are too numerous to put on a section, but the principal ones and the characteristic structure are represented in the stretch from mile 215 to mile 245. Certain portions of it, such as from mile 220 to mile 235, are comparatively simple because of the domi-

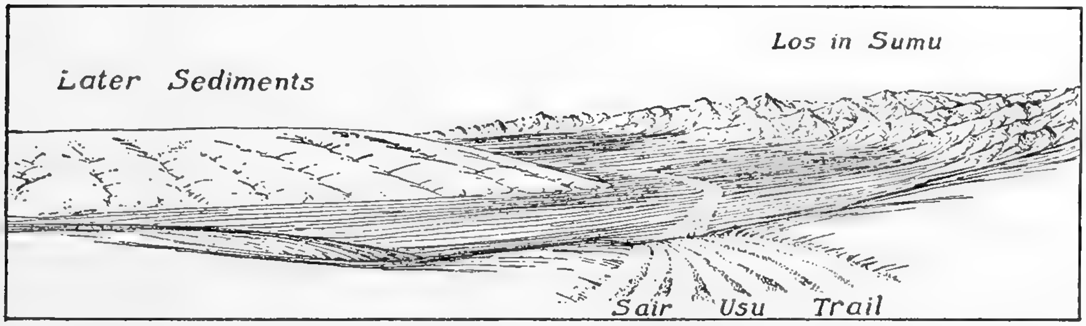


FIGURE 73.—Margin of a sediment-basin at Los in Sumu. The Sair Usu trail follows an inner lowland between oldrock hills on the north and the beginning of a broad basin of sediments on the south. The trail is marked by many narrow parallel camel paths.

nance of the massive bathylithic granite, whereas other less extensive portions, such as that from mile 240 to mile 245, are much more cut by a variety of intrusives (Fig. 75). From mile 248 to mile 253, Jurassic conglomerates and sandstones form the floor again, dipping to the southeast.

The interval between mile 214 and mile 248 appears to represent a stripped or eroded portion of the old floor which probably at one time was covered with Jurassic strata. From mile 253 to mile 262, the country is formed of a complex of porphyries which either have cut through or peep through the Jurassic conglomerates and sandstones, leaving scattered patches of Jurassic strata, such as the strip from mile 256 to mile 258. One of the most complex portions lies between mile 259 and mile 262 in the vicinity of one of the wells of the Sair Usu trail. Here the Expedition pitched the camp which we named "the Camp of the Porphyry Hills" (Specimens 580, 581, A.M. 10269, 10270). The distance of 112 miles from the Ongin Gol to this point was covered in a day,—one of the longest runs in the summer's work. Nevertheless, the geologic route section was kept fairly true. It is a terrific task to unravel more than a hundred miles of such structure in a working day. The geologist finds himself completely exhausted, and even dreams of underground structure, of strata and fossils, bathyliths, roof-pendants and ancient metamorphic revolutions, until the sun rises again on another day of geologic puzzles. One must try it to appreciate in full the effort that must be made to keep the story straight.

Beyond mile 262, essentially the same type of geological structure continues for a short distance; but in a few miles massive syenites and granites prevail over the porphyries, and, from mile 267, ancient crystalline limestones (Specimen 584, A.M. 10273), cut by granite, form the country rock for several miles. The rock is undoubtedly one of the very ancient formations, and apparently forms the roof of the bathylith, portions of which have encroached on the overlying rock and penetrated it far enough so that present-day erosion enables one to cross alternately patches of granite and strips of limestone. The limestones have various attitudes, but stand rather steeply and for the most part dip to the south or southeast.

Several shallow basins, with alluvium and sediments of perhaps Tertiary age, were crossed, but none of them is more than a few miles in extent. At mile 275, a patch of sandstone and conglomerate suggests the presence of a wedge of Jurassic strata, but an abrupt change is made to the older formations with limestones, granites and schists as the dominant country rocks (Fig. 76). A patch of flat-lying sandstone at mile 279 suggests that Jurassic strata formerly lay over this whole country, and that since being stripped off, the additional dissection has not been very great. The crystalline limestones and interbedded schists are probably the Wu T'ai (Willis, 1907, II, page 4); they are folded and crumpled, showing all the complexity usually present in formations older than the graywacke series. The best exhibit of this series of formations is found from mile 280 to mile 285 of the itinerary. Smooth sediments then cover the floor for a few miles, but it reappears at mile 292, and thence for thirty or forty miles to Sair Usu there is a succession of changes from limestones to schists cut by granites and in places by later porphyries (Fig. 77). The structure runs simply enough, but with a great showing of granite for the first twenty miles, to mile 311, where the course of the itinerary changed from east to south (Fig. 77).

This change of direction was occasioned by our having departed somewhat from the main Sair Usu trail, along one leading too far north. The change to a southerly course was made at the intersection of this byway with the regular Urga-Sair Usu trail, and from that point a run of seventeen miles brought us to Sair Usu, a well-known caravan station on the edge of the desert. The same formations continue, represented by crystalline limestones, schists of various sorts, granites and porphyries. The general dip at first is southerly, but this changes at about mile 319 to a northerly dip which continues for several miles, and finally to a southerly dip again at mile 324, where the older floor passes beneath a cover of overlying sediments of uncertain age. The general quality of these sediments is about that of the Cretaceous beds of other places, and we surmise that this may be another Cretaceous area; but no other data in support of it were found, except a considerable warping of the beds, which seems to be more characteristic of the Cretaceous sediments than of later ones.

At Sair Usu, mile 326, a last junction with the caravan was made for

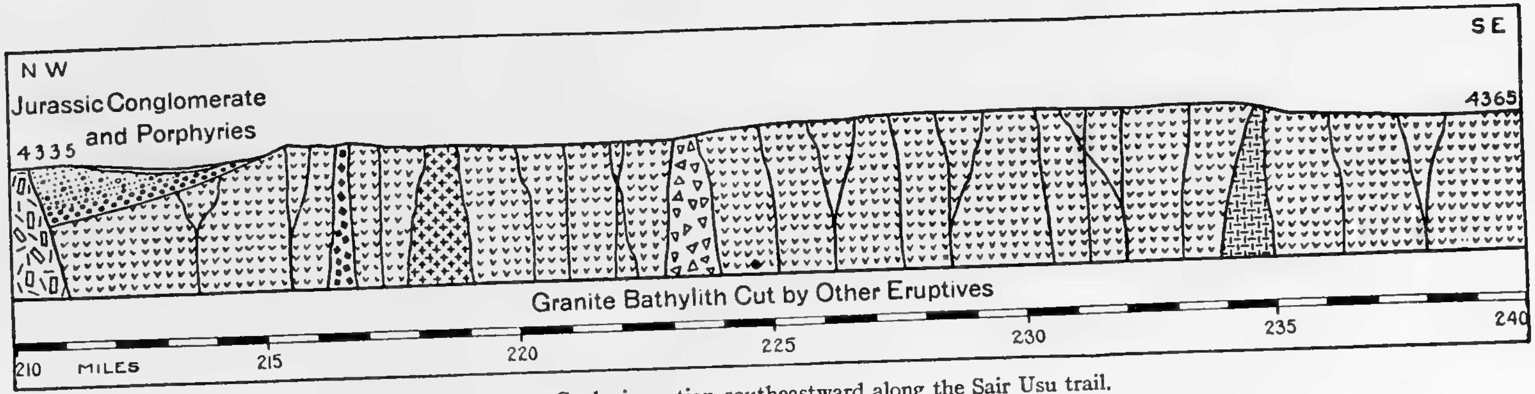


FIGURE 74.—Geologic section southeastward along the Sair Usu trail.

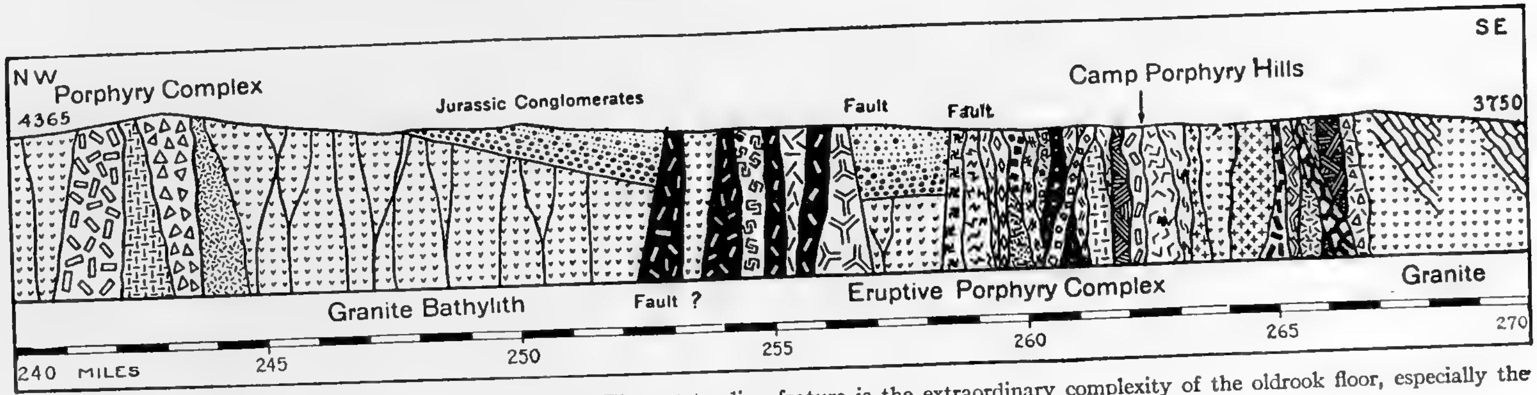


FIGURE 75.—Continuation along the Sair Usu trail. The outstanding feature is the extraordinary complexity of the oldrook floor, especially the abundance and variety of intrusive porphyries, which probably are of widely different ages.

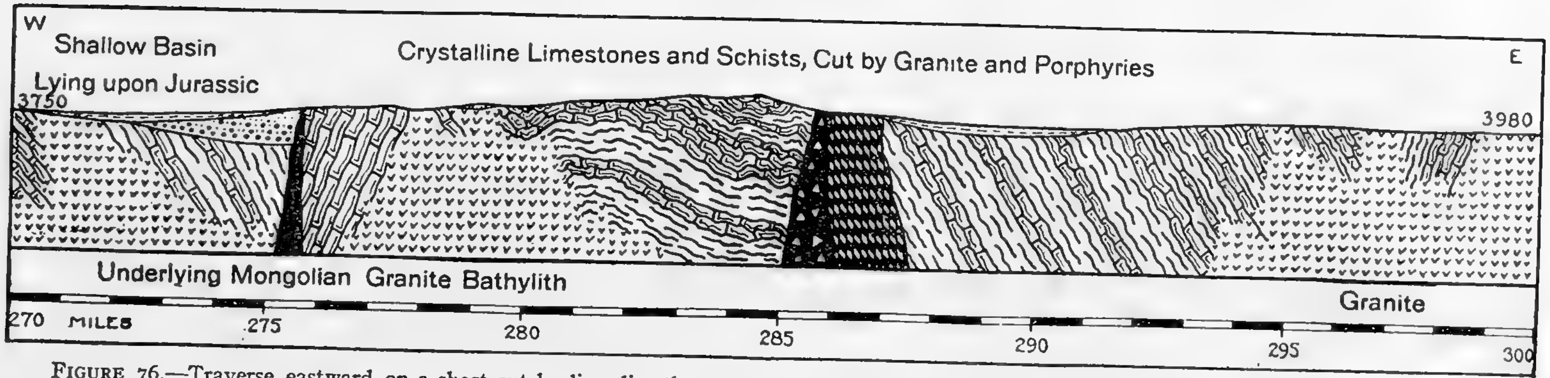


FIGURE 76.—Traverse eastward on a short cut leading directly toward the Urga trail. The section is a continuation of one of the most extensive areas of the bare oldrock floor. The upland surface represents the Mongolian peneplane.

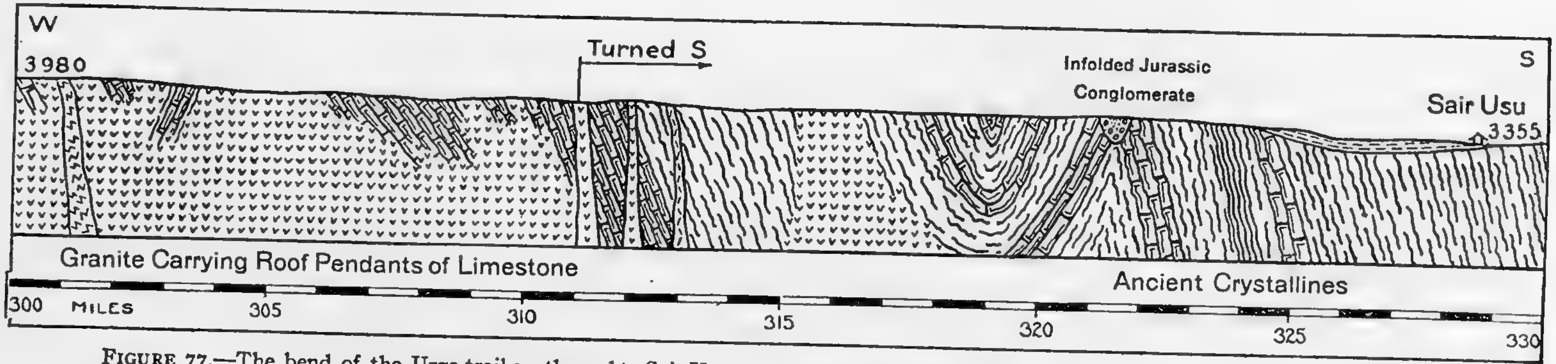


FIGURE 77.—The bend of the Urga trail southward to Sair Usu. The broad exposure of complex ancient rocks shown in figure 76 continues.

taking on supplies, and from this point on to Kalgan the run was made without further additions. The geologists took advantage of the opportunity to examine the strata of the basin and the adjacent hills. It was then found that the bare hillsides seen at a distance east of the trail are weathered ancient rock. The basin sediments, beginning somewhere in the vicinity of mile 324, yielded after diligent search traces of fossils judged to be plant remains. These beds are considerably deformed, and are made up largely of pebbly sandstones bound with lime (Specimen 602, A.M. 10291). The proportions of sand, lime and clay vary greatly, so that the sediments grade from sandstones to limestones and shales. The shales are of many colors, and some of the dark carbonaceous beds are almost paper shales. This quality, together with their structural relations, the occurrence of limy layers, and the finding of plant remains, leads us to believe that the strata belong to a Cretaceous basin, the extent of which is as yet quite unknown, but which continues in the vicinity of Sair Usu along the trail for more than five miles.

CHAPTER X

FROM SAIR USU TO KALGAN

THE trip of 535 miles from Sair Usu to Kalgan, which was begun September 7, occupied twelve days, including brief stops for geologic and palæontologic inspection of promising localities. The journey was made over the regular caravan trail, which is intersected by very numerous local trails and minor caravan routes, so that the most direct course is not readily followed without local guides. This region is more prosperous-looking than that in which the Expedition had worked for the last two months. One meets travelers frequently, and sees occasional villages, lamaseries, temples, and local shrines.

PALÆOZOIC STRATA

The traverse from Sair Usu crosses later sediments between mile 326 and mile 327, and in general topographic features there is no very striking break for a short distance farther; but hills appear on the south side of the trail, and the older floor of schists and limestones comes to the surface again at about mile 330 (Fig. 78). Apparently this is just a stripped portion of the old floor, because sediments appear again from mile 333 to mile 336, succeeded by another stretch of schists.

At mile 337, however, an entirely different formational type was found. At a cliff of fossiliferous limestone just south of the trail, hasty inspection revealed a fauna indicating Palæozoic age. The sandstone beds and conglomerates beneath the limestones lie unconformably on the ancient schists. The column at this point, therefore, is represented by: conglomerates at the base, approximately 150 feet thick; sandstones, 200 feet; cherty limestones, richly fossiliferous, 500 feet; gray limestones, 200 feet; very dark brown limestone and sandstone, 200 feet; yellow dolomitic limestone, 100 feet; fossiliferous, pink, granular limestone, 500 feet; dark brown limestone, 200 feet. This section is suggested by the outcrops that stretch from mile 337 to mile 338.5. The structure is that of an anticlinal fold, breached at the crest so that the schists are exposed along the stripped arch.

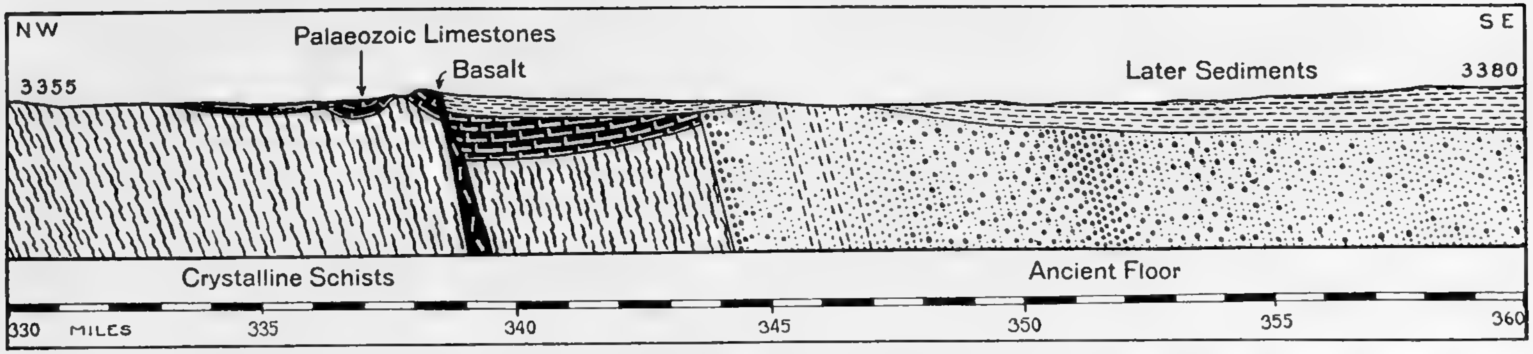


FIGURE 78.—Geologic section from Sair Usu southeastward on the Kalgan trail. An infolded and faulted remnant of late Palæozoic strata is crossed between miles 336 and 339. The covered continuation of the limestones eastward is conjectural.

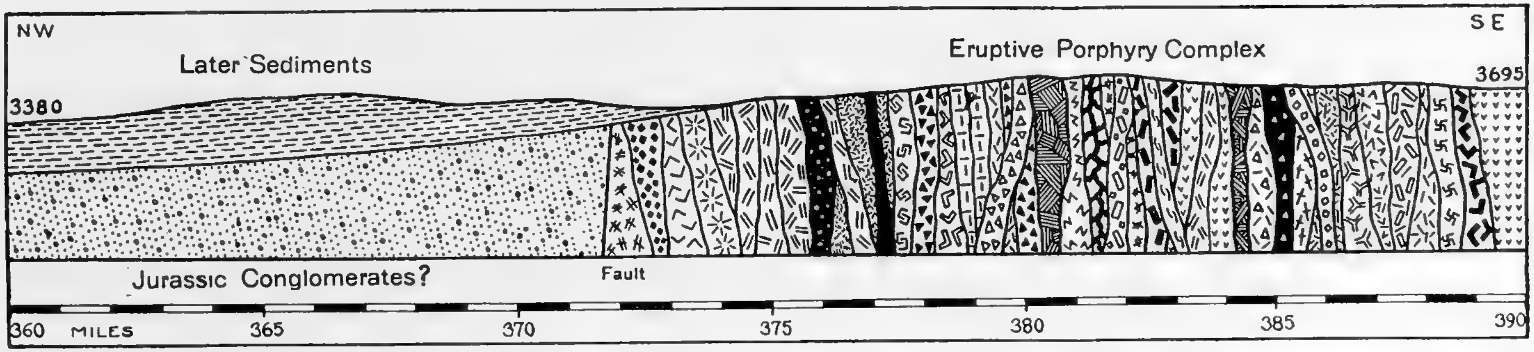


FIGURE 79.—Continuation along the Sair Usu to Kalgan trail. The outstanding feature of this section is the enormous extent and great variety of rock types, and their obscure structural relations.

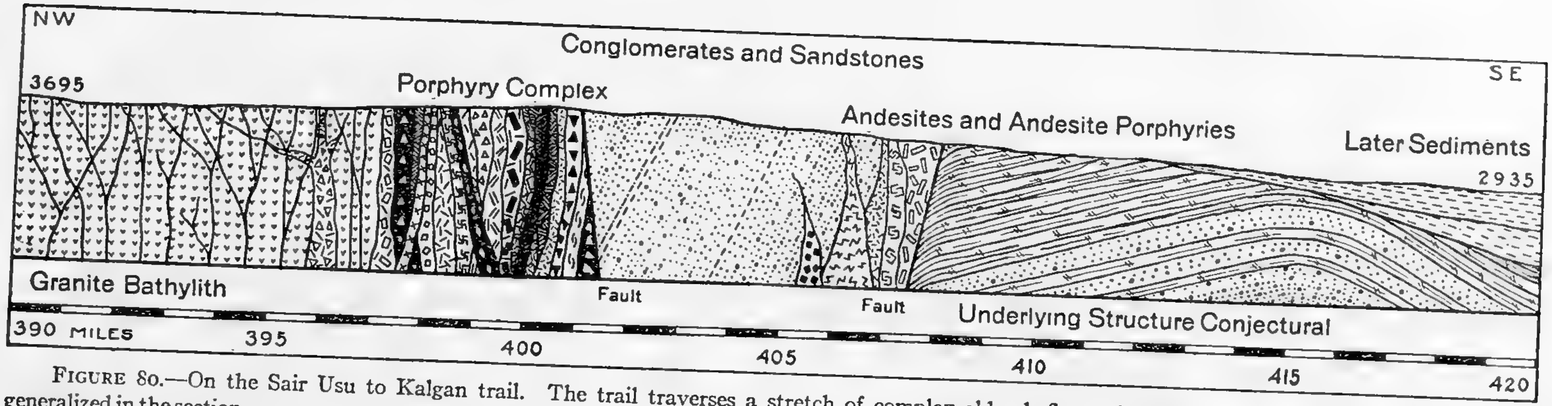


FIGURE 80.—On the Sair Usu to Kalgan trail. The trail traverses a stretch of complex oldrock floor with obscure structural relations which are generalized in the section.

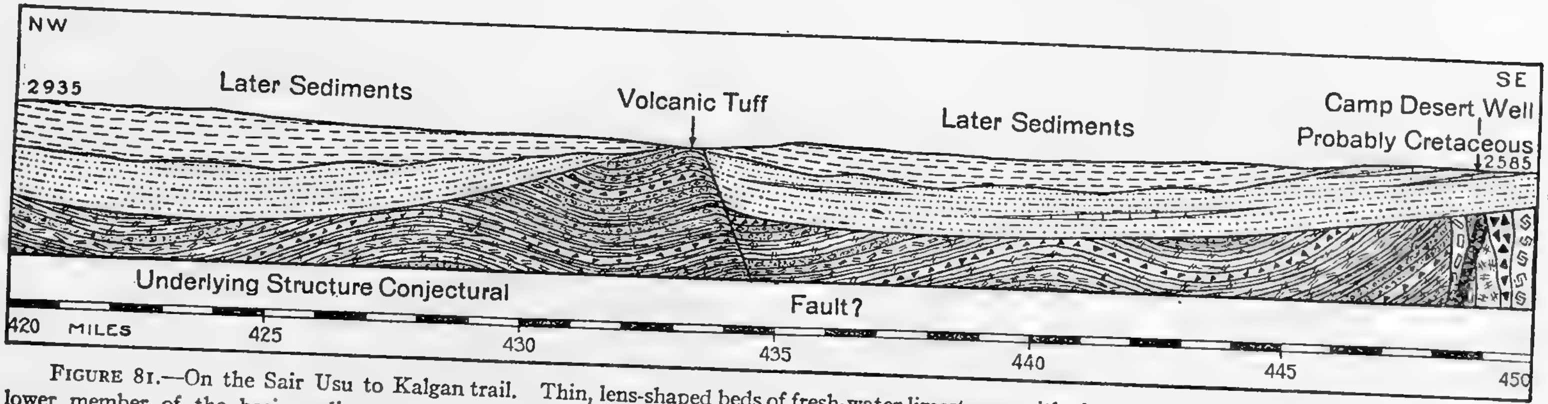


FIGURE 81.—On the Sair Usu to Kalgan trail. Thin, lens-shaped beds of fresh-water limestones, with obscure traces of plant remains, are found in the lower member of the basin sediments.

This was the first time in the whole summer's itinerary that determinable Palæozoic strata were discovered in place. Only one other piece of Palæozoic rock, and that a loose fragment, had been found up to this time. The fossil content of these beds near Sair Usu has proved on later comparison to be of Dinantian (Mississippian) age. Fossils are abundant, and undoubtedly an extensive collection of later Palæozoic forms could be obtained from this locality and a much more extensive series of beds could be made out if the strata were followed along the strike, either to the east or to the west. We propose to call these beds the Sair Usu formation.

CONTINUATION OF TRAVERSE TO ARDYN OBO

Along the course of the trail, however, the strata are cut off abruptly at mile 335, either by a fault or by an igneous outbreak, or by both; and here a basin of later sediments begins, which continues for at least thirty miles. Perhaps this is one edge of a down-dropped fault block, or a very sharp warp of the ancient floor, causing the retention of the sediments. It is not possible anywhere along the trail to determine either the age or the thickness of this sedimentary deposit. It is probably comparatively thin, for from mile 345 to mile 347 the floor is stripped by present-day erosion, exposing slaty and shaly rock with limestone layers and conglomerates standing on edge. Just what these rocks represent in the series of formations could not be determined. They are not exactly like any seen elsewhere, but may be some facies of the Palæozoic strata associated with the limestones seen farther back along the trail at mile 337.

Except for this window exposing the ancient floor, the later sediments continue with rolling topography to mile 374, where porphyries of trachytic composition come from beneath and form the floor for some distance. From mile 374 to mile 389, a complex of porphyries forms the country rock (Fig. 79). The porphyries are brecciated and brittle, cracking into small chips. They are prevailingly fine-grained, of very great variety, and belong to many different individual field units—too many to illustrate on the scale used for the cross-section. Some of the units show flowage lines, but for the most part there is little structure to be made out, except that these porphyries cut one another in a most intricate way, making an exceedingly confused structural complex.

From mile 389 granite is the dominant rock for several miles (Fig. 80). Its relation to the porphyry complex is not clear, but in general lithologic appearance the porphyries seem to correspond in some measure to the dikes that almost everywhere else are prominent in granite areas. A simpler formation of bathylithic granite, cut by dikes, continues to mile 397, where a change to complex porphyries again takes places and continues to mile 401.

From mile 401.5 to mile 407, conglomerates and sandstones, standing on edge but dipping steeply to the north, are crossed by the trail. This makes a stretch of five and a half miles directly over the edges of strata whose structural relations are not fully determined. Probably they are all of Jurassic age, and this is another of the down-dropped blocks so often seen carrying strata of this type.

Volcanic rocks cut in again at mile 407, and continue with a porphyry complex and volcanic flows of obscure structural relations for several miles, until the edge of a basin is entered at mile 413, and from that point later sediments form the terrane for forty miles. The underground structure is simple, but the profile is more varied than in most sedimentary basins. Erosion has exposed the strata at numerous places, so that one can see their character, and at one point, mile 433, the ancient floor comes to the surface, apparently indicating that the basin is considerably deformed (Fig. 81). Judging from the physical appearance of the strata, a part of these sediments should be of Tertiary age, and a portion underlying, with somewhat more indurated habit and somewhat greater deformation, containing occasional limestone layers, is probably of Cretaceous age. Certain of the thin-bedded limestone layers carry traces of fossils (Specimens 636, 637, A.M. 10325, 10326) of a type similar to specimens found north of Artsa Bogdo and subsequently shown to be plant remains. On the north margin of Artsa Bogdo we had found beds of fresh-water limestone, carrying obscure plant remains intercalated in the basin sediments (see page 151).

Sediments of Ardyn Obo

At mile 453, the ancient schists, gneisses, and porphyries of the floor appear at the surface again and continue to mile 458 (Fig. 82). This ground is very smooth and almost as level as the surface of the sediments themselves. Sediments come in again at mile 458, and continue, with only one break at mile 473, to Ardyn Obo, where an escarpment of these sediments exposes more than 200 feet of strata (Fig. 83). Here fossils of Lower Oligocene age were found (Fig. 86, and Plate XXI).

The bluff of Ardyn Obo can be seen south of the road, extending east and west for many miles. At mile 487, the direction of the scarp changes sharply and lies almost north and south (Fig. 84). Upon the cliff-top at this abrupt corner, which, high over the vast lowland, looks like a cape on a seacoast, the Mongols have built a large obo which can be seen for twenty miles (Fig. 85). An obo is a pile of stones beside the road, in which every stone represents a prayer to Buddha. Some are mere heaps, while others are built like towers, with minor piles around them. Pitiful sacrifices of the few things the desert can spare are added by pious wayfarers—torn strips of garment,

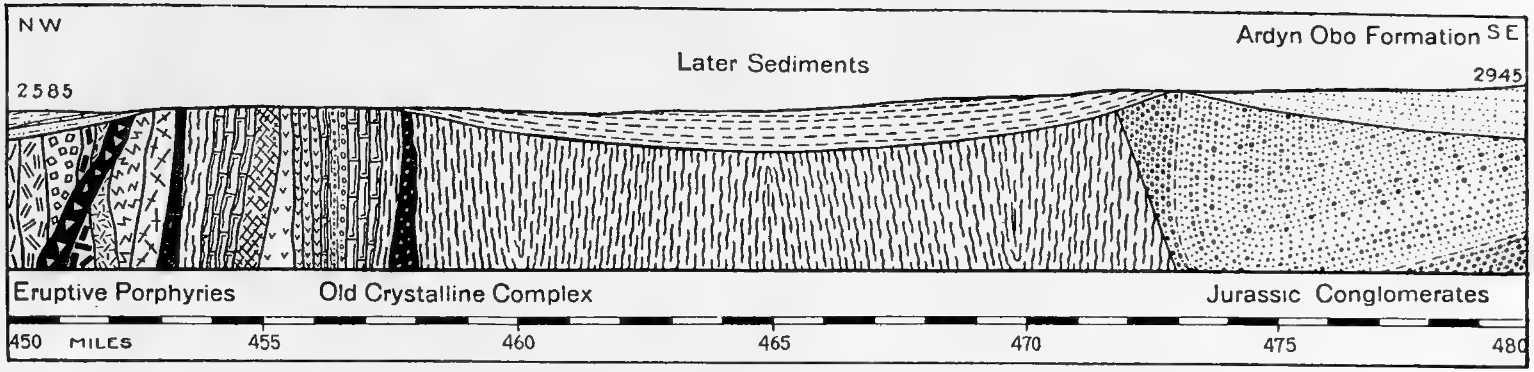


FIGURE 82.—On the Sair Usu to Kalgan trail, to the edge of the Ardyn Obo basin.

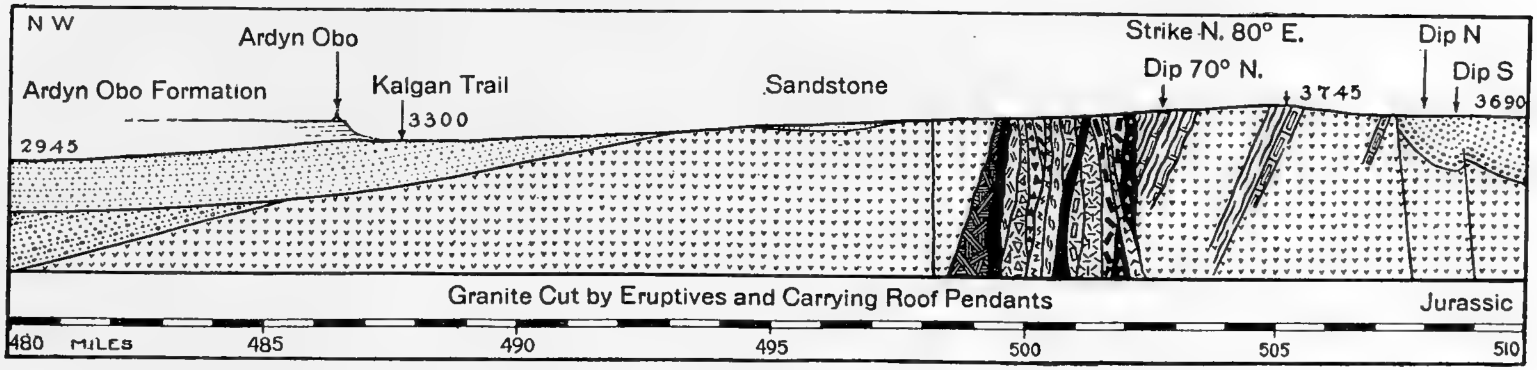


FIGURE 83.—Geologic section southeastward from Ardyn Obo, along the Kalgan trail. The most prominent feature of the landscape is the Ardyn Obo scarp, which continues toward the west for more than 20 miles.

nose-thongs of camels, small Chinese coins, and sticks from broken yurts or carts. The obo serves not only to mark a sacred spot, but is of serious importance to the traveler as a cairn to indicate the trail. A Mongol guide will tell

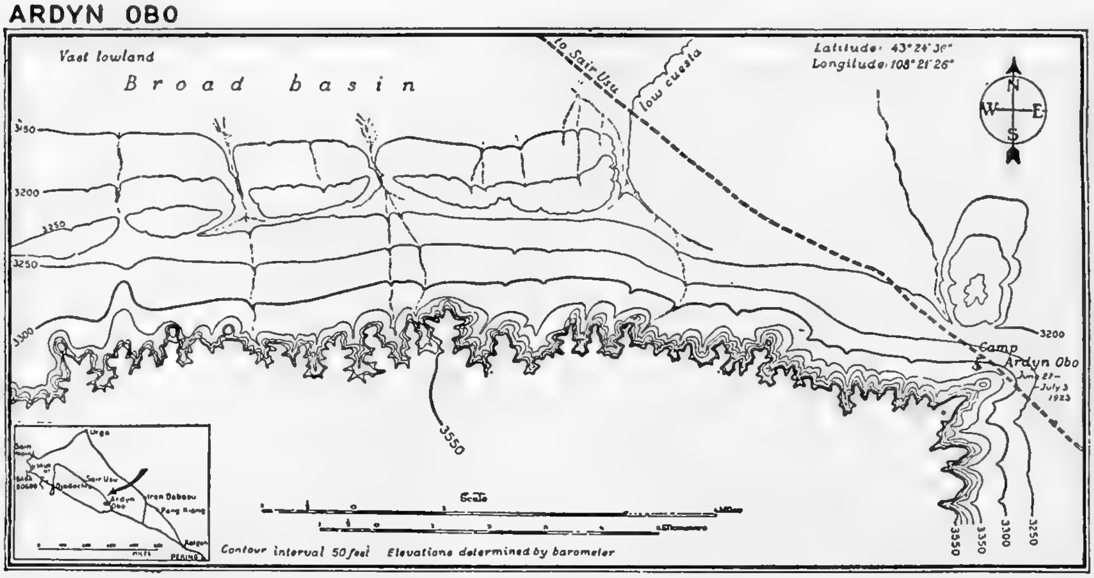


FIGURE 84.—Map of the Ardyn Obo locality.

the way in terms of obos, no less than of temples, wells, and topography. The impressive pile at mile 487 is the Ardyn Obo, the "prayer pile of jewels," and gives the district its name. The name was also adopted for the stratigraphic unit. The word "ardyn," meaning "jewels," proved to be the same word which we had spelled "irdin" farther east. It refers to the glittering,

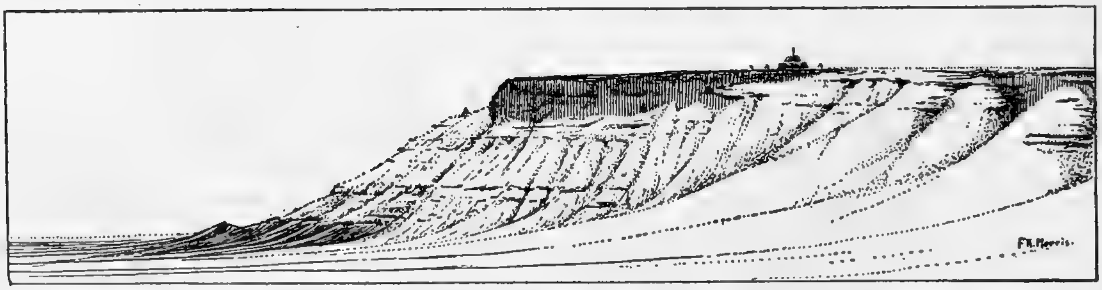


FIGURE 85.—Field sketch, made at Ardyn Obo from the lowland, showing the abrupt cliff-like scarp and the very slight back-cutting of the young gullies.

highly polished pebbles of quartz and chalcedony which are found in the upper sandstones of the formation.

Three days were spent at Camp Ardyn Obo (Plate XXI), to enable us to make collections and additional studies. The strata are well exposed, so that a detailed column of the beds forming the escarpment could be measured (Fig. 86). They consist essentially of two members, sandy clays below, and cross-bedded sands and gravels above. All were probably water-borne sediments, and the channeled and cross-bedded upper member testifies to vigorous

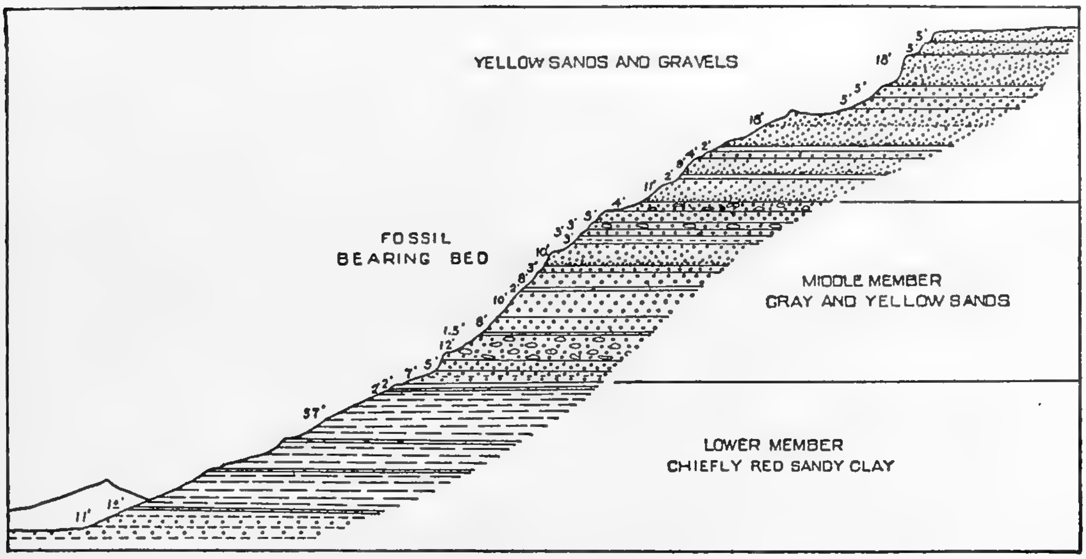


FIGURE 86.—Geologic section at Ardyn Obo.

stream work. Consistently with this interpretation, no associated skeletons, such as were common at Djadokhta, were discovered here—only scattered bones, some of which were much worn, as though they had been rolled about by streams. Caches, or pockets, of bones were found in the bottoms of the old stream-channels, the cross-sections of which are clearly seen in the bluff (Plate XXI, B). Although the fauna includes an aquatic rhinoceros, a large titanothere and several carnivores—enough of a fauna to determine the approximate age as Lower Oligocene—the locality is not prolific in fossil forms, and the great majority of the beds seem to be entirely barren.

At this point, also, there is an exceptionally good exhibit of characteristic erosion forms, and some of these have been made use of in our studies of erosion and physiographic history (Chapter XIX). The bluff itself is very simple, steep and straight, and extends unbroken except for minor short gulches, as far as the eye can reach. It is topped by a gravel-covered, smooth surface which represents the Gobi erosion plane.

ARDYN OBO TO SHARA MURUN

On leaving Ardyn Obo the trail continues over sedimentary strata of the same sort to mile 493, where, only three miles from camp, granite and granite gneisses cut by dikes come to the su face again. This change makes no impression on the topography, for erosion has simply stripped certain of the irregularities of the old floor, and these portions merge into the general level without any noticeable change of feature.

Again, at mile 495, sediments are reached in a shallow basin extending for two miles. They are unfossiliferous sandstones, which, from the character of the rock, were judged to be probably of Cretaceous age. From mile 497 onward, the granites of the floor form the surface again, and erosion has left upstanding, jointed remnants that look like the ruins of giant masonry, conveniently referred to as "monument granite." The same type of erosion and relief was noted at several other places along this traverse. At mile 500, a gabbro-diorite cuts into the granite, and then there follows for two miles a great igneous complex of many rock varieties, which in turn is succeeded by a series of limestones and schists, dipping steeply to the north. Strips of this kind of rock are repeated several times in the next five miles, separated by occurrences of granite. The granite is probably of the same bathylithic type that has been noticed over so large a portion of the Mongolian territory, and the occasional strips of metamorphic rock are probably only portions of the roof not wholly destroyed in the peneplanation that preceded the deposition of the later sediments.

An abrupt change takes place at mile 507, where sandstones come in, which we believe to be of Jurassic type; but within three miles they are covered by alluvial material and perhaps shallow basin sediments, which entirely obscure the older structure (Fig. 87). The basin is limited at mile 512, and again for many miles the trail crosses the ancient floor, consisting of limestones, quartzite schists, granite gneisses, shear-schists, and greenstones. They form a great schist-gneiss complex, including a large amount of greenstone sheared into schistose condition, with much smaller amounts of dolomitic limestones and other metamorphic rocks, including gneisses. Nowhere have we found so great a series of this type, and nowhere in the whole summer's work has so much greenstone been seen. The series probably belongs to the Wu T'ai system—perhaps very old Wu T'ai.

Farther along, at mile 519, red quartzites and slates are intercalated with the greenstone schists, but greenstone predominates to mile 522, a distance of three miles. Quartz veins and lenses are abundant, but they appear to be barren. Toward the south the greenstones pass into brown, siliceous metadolomites, sericite schists and porphyritic greenstones (Specimen 673, A.M. 10362), conglomerates, and tuffs or tuff-schists.

From mile 524 the trail passes over much ground covered with pebbles that might be derived from Jurassic conglomerates, but no outcrops were seen and it was not possible to determine in this stretch what the structure is.

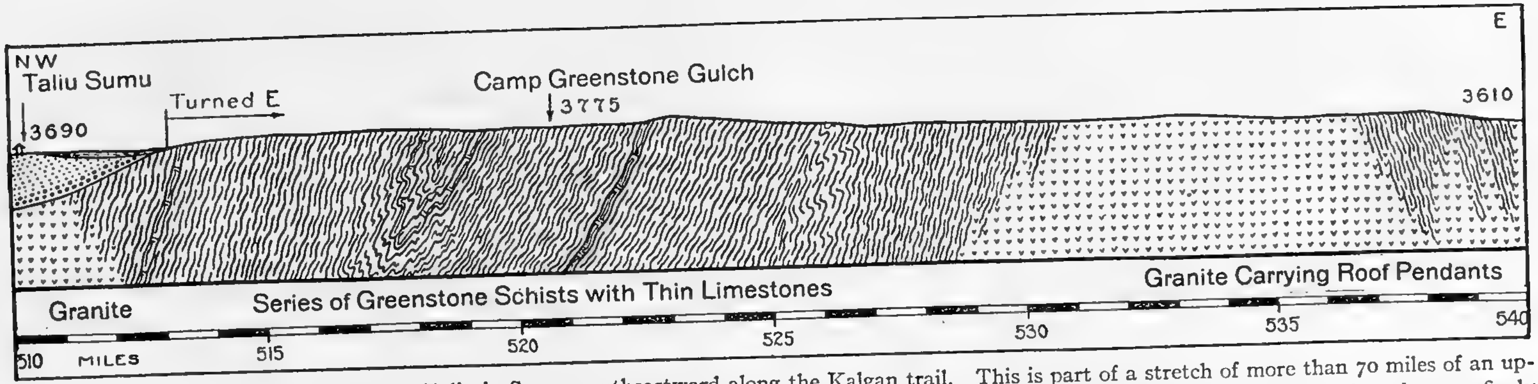


FIGURE 87.—Geologic section from Taliu in Sumu, southeastward along the Kalgan trail. This is part of a stretch of more than 70 miles of an up-warped block of the oldrock floor, lying between the Ardyn Obo basin and the broad Shara Murun basin on the east. This is the beginning of a very finely dissected portion of the old Mongolian peneplane. The multitude of hilltops rising to an accordant level suggested at once the field name "Choppy Sea," by which this area was known to all members of the Expedition.

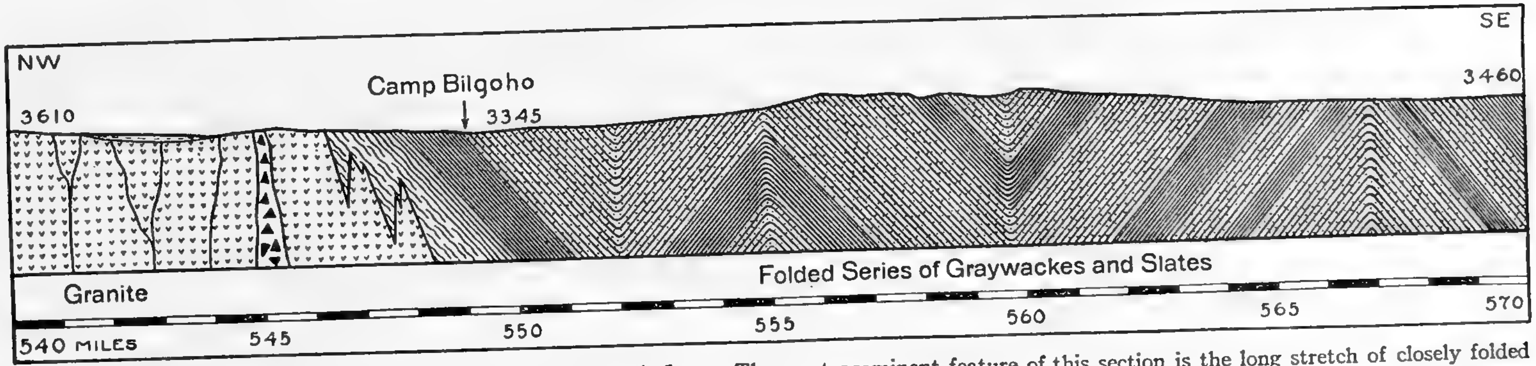


FIGURE 88.—Continuation southeastward over the oldrock floor. The most prominent feature of this section is the long stretch of closely folded graywackes and phyllites which are almost continuously exposed in the "Choppy Sea" hill-country for 25 miles.

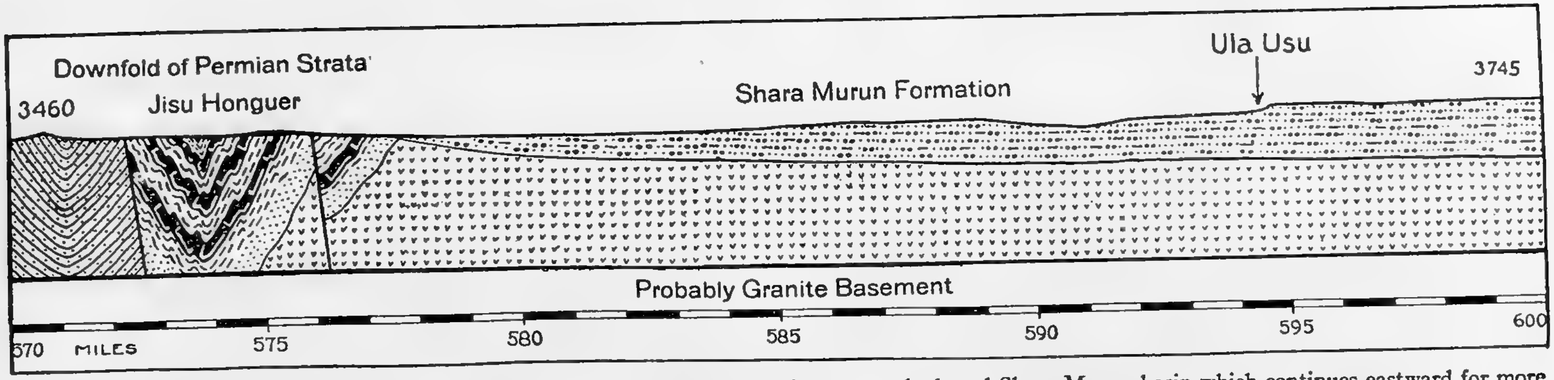


FIGURE 89.—Geologic section from Jisu Honguer to Ula Usu. The section enters the broad Shara Murun basin which continues eastward for more than 80 miles. This is the only place where the undoubted late Palæozoic strata and the typical graywacke series have been seen in contact.

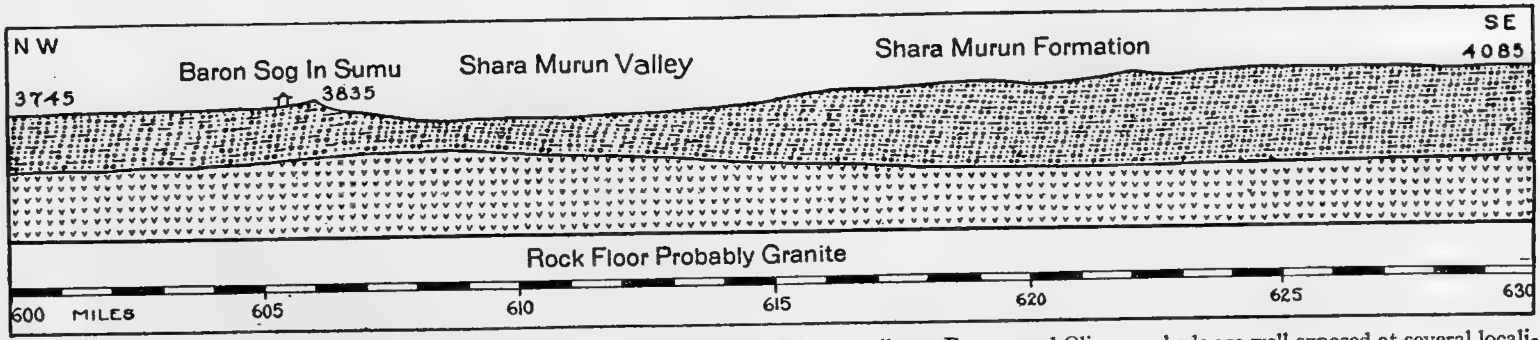


FIGURE 90.—Geologic section from Baron Sog in Sumu across the Shara Murun valley. Eocene and Oligocene beds are well exposed at several localities, and yield a rich fauna characterized by titanotheres.

The next outcrop of definite character is a quartz-porphyry at mile 526, and the ground is covered again for several miles, making it impossible to determine its exact character. Ridges seen in the distance at the side of the trail, indicate formations with a prominent structure, dipping to the north. Fragments, chiefly of mixed schists, are washed in from the adjacent country and lie about on the ground. Among the fragments are pieces of limestone, some of which are fossiliferous, and it is judged from this that Palæozoic strata are exposed in the higher ground on the east side of the trail. The covered ground extends to mile 531, and then granite, cut by dikes of various porphyries, is exposed again in smooth topography and is the chief type for several miles. At mile 538, the trail crosses green schists cut by granite; the schists probably represent roof-pendants extending down into the bathylithic granite. This kind of country continues for several miles, with areas of granite, short stretches of covered ground, and the usual dikes and remnants of the ancient roof.

At mile 546 an entirely new series begins, represented by schists, quartzites, phyllites, and slates, developed on an enormous scale (Fig. 88). At first, reddish slates, and phyllites with considerable vein quartz predominate; the strike is N.80°E., and the dip is northerly. Camp was pitched here at mile 549, on the Bilgoho flats. The same formations continue, becoming gradually more granular and dipping to the south. Farther along, the quality changes to typical graywacke and gray sandstones, while reversals of dip indicate that the series is folded. This graywacke quality predominates in the portion of the series crossed from mile 554 to mile 560. There are marked differences of color, and the quality is much more variable than has been seen elsewhere in the so-called graywacke series. Phyllitic slates are abundant, and in some places the rock is sheared almost to a schist (Plate XXII, A). It is possible, of course, that there is more than one series represented in this stretch of ground, which continues to about mile 571, but in the time given to it no definite formational separation could be made, and it is assumed that this whole succession from mile 547 to mile 571 is equivalent to the graywacke series as typically exposed on the Tola River far to the north.

Palæozoic strata of Jisu Honguer

Beyond mile 571, the strata change abruptly—probably along a fault (Fig. 89). The graywackes, seamed with multitudes of white quartz veins, give place to a series of simpler sandstones, fine fissile shales and gray limestones, striking a little north of east (Specimens 691, 692, 693, A.M. 10380, 10381, 10382). The new series contains none of the quartz veins seen in the graywackes. The shales and sandstones are barren, but the limestones are richly fossiliferous. A. W. Grabau later identified the Permian Lyttonia fauna in the fossils collected here, thus proving that the beds are not correlated with those of Sair Usu. The district is called Jisu Honguer by the Mongols, and the name Jisu Honguer formation was therefore chosen for these Permian beds. In the second season the geologist stopped for several days at this place, mapping and recording the rocks and collecting their fossils. The beds are very strongly folded; the folds are overturned toward the south and are broken by two series of faults—an older set of fold-thrusts parallel to the strike, and a younger set of cross-faults. The formation occupies a narrow strip bordered by fault-contacts between the granite hills on the south and the graywacke series on the north. At about mile 576, the entire series passes under sediments which, fifteen miles farther east, carry a rich fauna of later Eocene vertebrates (Fig. 89).

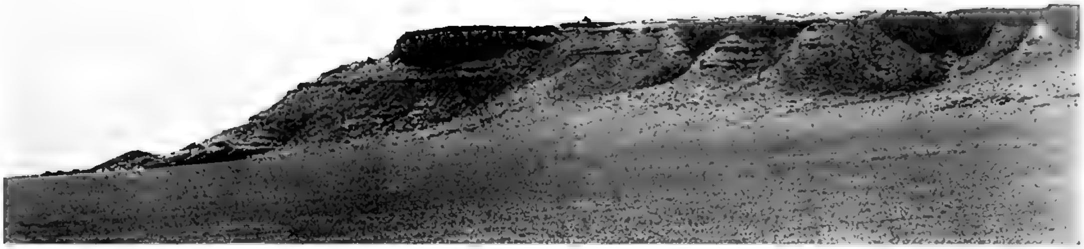
Tertiary sediments of Shara Murun

There is an escarpment at mile 589, where beds of characteristic Tertiary habit are exposed (Plate XXII, B). The gullies of the badland area descend northward into a hollow lowland of large extent, exposing beds of red, greenish, and purple clays amazingly rich in vertebrate fossils. Above the clays lie white and gray sandstones which carry fewer fossils. In our swift reconnaissance no adequate study of these beds could be made, but the place was noted and reserved for careful search in the season of 1923. We have called them the Shara Murun formation, and Osborn and Matthew consider them to be of Eocene age—rather younger than the Irdin Manha beds.

At this point the trail climbs to the top of the escarpment and crosses a stretch of level Gobi erosion plane from mile 595 to mile 606 (Figs. 89 and 90). This ground is underlaid in its entire extent by Tertiary strata such as were seen at mile 593, and they are found again at mile 606, on the opposite side of this broad mesa, where a very prominent bluff exposes a few hundred feet of white and reddish sands and clays.

The Shara Murun, a broad valley 300 feet deep, had to be crossed from mile 606 to mile 615. The course of the traverse across the Gobi erosion plane had been approximately S.60°E., but across this valley the direction was changed to S.80°E., and on climbing the escarpment beyond mile 615 not much difference was made in the course, except to turn a trifle more to the south. The country is underlaid by sediments of later type but of undetermined age, as no sufficiently good exposures were seen to warrant closer investigation. The upland, across which the traverse lies, is undoubtedly again the Gobi erosion plane, but the ground, as it reaches away indefinitely in every direction, is more rolling than in many other places. There is an older topography still preserved on this upland, with shallow valley courses apparently

PLATE XXI.



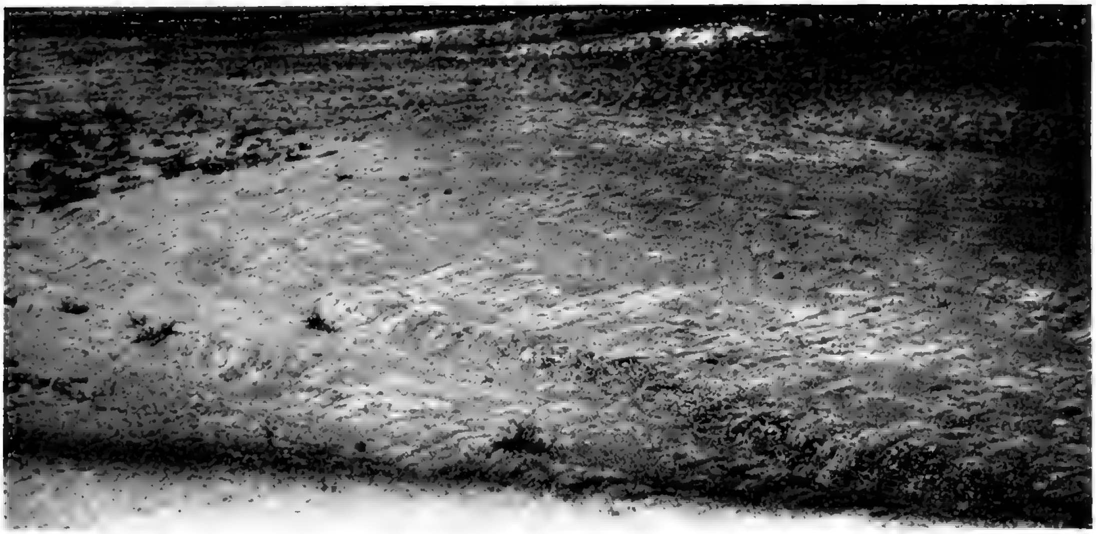
A. ARDYN OBO.

The upland surface is the level Gobi erosion plane. The heap of stones on the upland is the Ardyn Obo, or "prayer pile of jewels," which gives the locality its name and for many miles is the traveler's chief guiding landmark.

B. STRUCTURAL DETAIL OF THE SCARP AT ARDYN OBO.

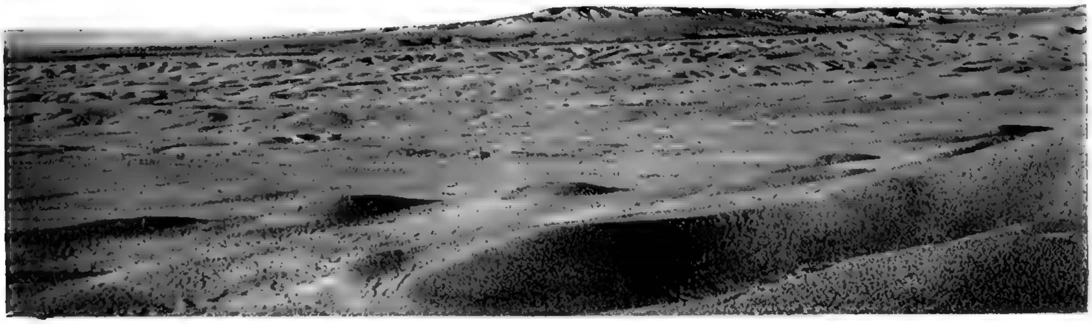
The crossbedded sands and gravels exhibit channeling. Traces of contemporary plant roots have been preserved as tubular concretions which are best seen at the right. An important find of Oligocene rhinoceros skulls was made in one of these ancient channel fillings, where Mr. Granger and Mr. Andrews are seen at work.

PLATE XXII.



A. BILGOHO.

The bare rock floor near Bilgoho bevels the upturned edges of folded slates and phyllites. Deeply worn grooves made by caravans are seen in the foreground.



B. BADLANDS OF THE EOCENE SHARA MURUN FORMATION AT ULA USU.

unrelated to the more pronounced valleys, such as the Shara Murun which is now dissecting the country.

SHARA MURUN TO KALGAN

This rolling upland continues for many miles. The camp of September 15 was pitched beside the trail on this upland country, at mile 632, and the journey the following day continued over the same kind of ground to mile 657, twenty-five miles farther along (Fig. 91). At some point within this distance the quality of the ground changes, but because of the soil cover and the increasing failure of outcrops, the change was not noticed until mile 657 was reached, where granite, quartzite, limestone schists, and other associated schists again form the floor.

Not many observations were made, but occasional opportunities for identification indicate a complex floor of ancient rock, probably Wu T'ai, with schists, limestones, quartzites, and granites as the dominant elements (Fig. 92). For the next twenty miles or more no great change is registered. Long stretches of ground are covered with disintegration débris, but some indication of rock character can be made out from the fragments that lie scattered about, and there is every indication that the underlying structure is complex. In the last few miles approaching the next camp, granites dominate, weathered into "monument granite" form.

The day's travel was accomplished under extraordinarily trying conditions. The autumnal storms had set in; the journey began in rain which changed to snow, with a tremendously strong, cold wind, and ended with everyone chilled through, for the party had not yet changed from midsummer clothing. Less than two weeks had elapsed since almost tropical temperatures had prevailed. As a result of the day's exposure, those who were least protected were so thoroughly chilled that there was real danger of more serious consequences, and the experience served as a broad hint to use all possible speed in reaching Kalgan.

From Camp Granite Monument, at mile 697, the trail crosses granite with patches of quartzites and schists as xenoliths and pendants, for the next twenty miles or more (Fig. 93). The structure appears to be simple; granites greatly predominate, with numerous roof-pendants, the usual porphyry dikes, and the normal variations in quality.

Chinese settlements

Within a day's traverse, the desert country gradually greened into the typical Mongolian grassland, and at about mile 725 the first cultivated fields of the encroaching Chinese came into view (Fig. 94). From this point onward the occupants of the country are Chinese, and, except for travelers along the trail, one sees no Mongols. The outermost patches under cultivation are scattered, and clearly represent a pioneering experience; but within a very short distance there appear extensive, well-cultivated fields of grain with ripening barley, oats, flax, and millet. It is noted also that the soils look rich and heavily cover the rock floor. Outcrops now are rare, and it is more difficult to determine the structural character of the country in a reconnaissance as rapid as the return journey required. Only occasional observations could be made from this point onward. Wherever granites are present, outcrops could usually be seen at the side of the trail. Occasionally, as the trail crossed them in the next thirty miles, limestones, quartzites, gneisses, and schists could be identified. It is very evident, therefore, that the floor is made up of ancient rocks rather than of later sediments. Wherever the ledges are to be seen, they indicate closely folded structure and crystalline condition. This type of country undoubtedly prevails without material change, but also without possibility of very accurate correlation, to about mile 760 (Fig. 95). The trail at that point enters a prosperous agricultural plain dotted with Chinese villages. Its smoothness suggests a sedimentary basement, but the understructure is obscure.

At mile 773, the Expedition went into camp at the side of a small pond in the midst of a farming community, where fields of grain and general agricultural prosperity were the predominant features. In the distance one could see flocks of wild fowl, and as the whole aspect was that of a grain-farming region, not very unlike portions of our own Northwest, we named it Camp North Dakota.

In a single day the Expedition had returned from the barrenness of semi-desert to comfortable agricultural surroundings. For the first time in five months one could see cultivated plants being grown for food. The prosperity of this immediate country naturally suggests the possibility that a much greater portion of the Mongolian border might be adapted to the same purpose. This is undoubtedly true, and advantage is being taken of it by the Chinese, who are encroaching on this territory at the rate of two or three miles a year. How much farther this kind of cultivation can be extended is a serious question. The limits of farming without special adaptation to arid conditions appear to be not far beyond the present zone of occupation. Within two days' journey in our mode of travel the bounds would surely be reached, and cultivation beyond would have to be confined to local areas of special favor, where irrigation could be practised.

Certain it is that the Mongols themselves are not making this use of their own land, although there is evidence that irrigation was practised far inland in former times. Whether they ever will change their mode of life sufficiently

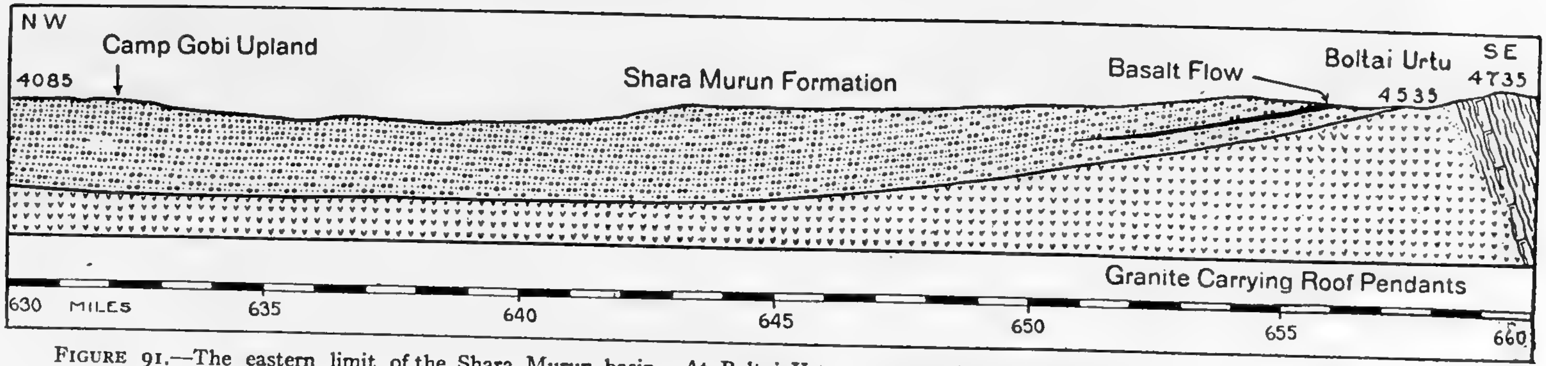


FIGURE 91.—The eastern limit of the Shara Murun basin. At Boltai Urtu a cross-trail runs north and south, connecting Iren Dabasu and Kweihwating.

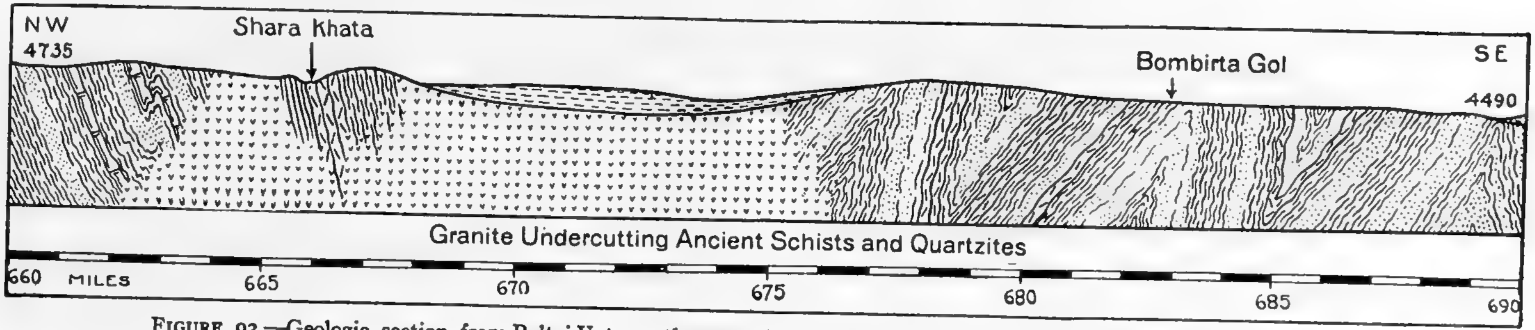


FIGURE 92.—Geologic section from Boltai Urtu southeastward on the Kalgan trail. The section crosses the stripped oldrock floor.

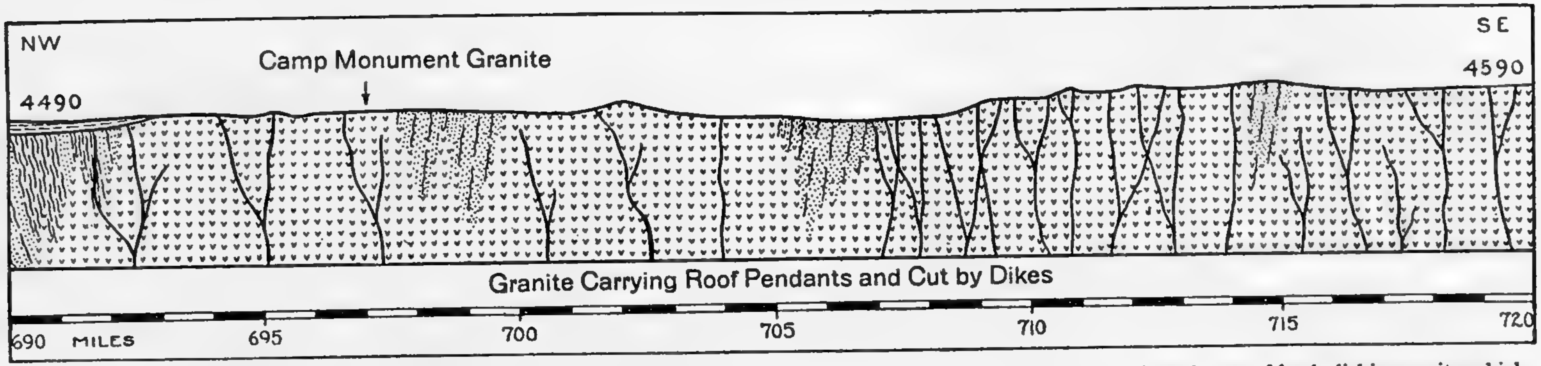


FIGURE 93.—Continuation along the Kalgan trail over the stripped oldrock floor. This is the beginning of a broad area of bathylithic granite which, with its roof-pendants, forms the country rock for more than 60 miles.

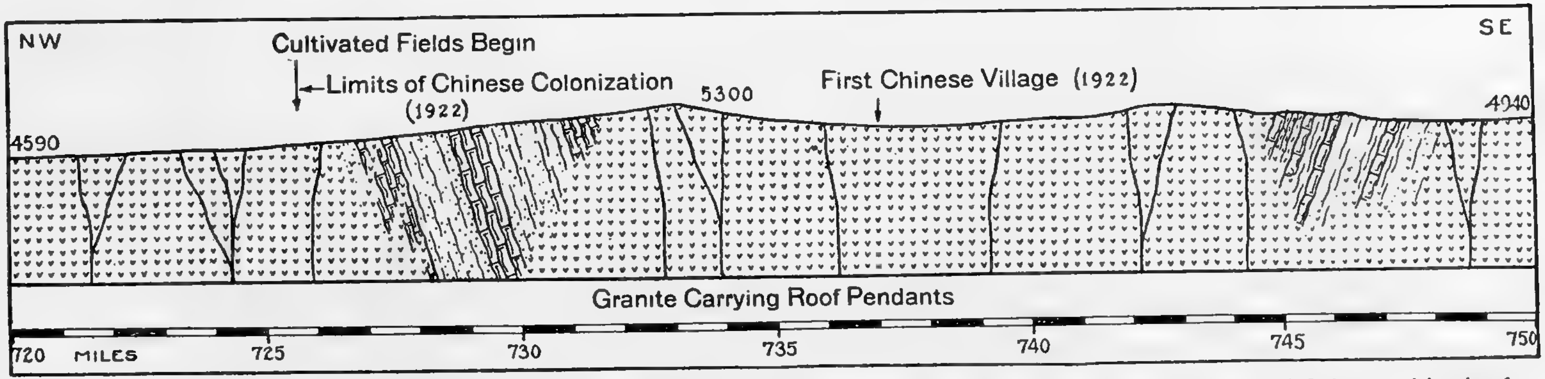


FIGURE 94.—Continuation on the Kalgan trail across the bathylith. Since 1922, when this section was made, the zone of Chinese cultivation has advanced many miles farther toward the interior.

to enter upon agricultural undertakings is extremely doubtful. It is certain, of course, in that case, that other peoples sooner or later will occupy the arable lands, and it is probable that the time is not far distant when the Chinese, on whom the pressure for an outlet is greatest, will claim most of them.

It is most amazing that these arable lands have lain untilled, on the very borders of a land where the struggle for existence has been so severe for generations. With an example of great agricultural competence before them, even at their very doors, the Mongol owners of these tracts seem never once to have tested this quality; and, on the other hand, the Chinese, even though visited by famine time and time again, and doubtless fully appreciating the advantages of additional agricultural facilities, seem to have avoided this encroachment. It is an almost unbelievable situation, for which there must be some special explanation. Perhaps the Mongols have been too fierce, and the unprotected outposts of unwarlike settlers could not maintain themselves against their raids. The region lies outside all the ancient walls, and many, many miles beyond the Great Wall of China, the existence of which throws some light on the same problem. A people with a desire for isolation so strong that they were willing to build such a vast, protective barrier, perhaps should not be expected to venture far into the barbarians' territory beyond; and it is equally reasonable to believe that a people outside, against whom such bulwarks must be built, were vicious enough to prevent any unwelcome encroachment. Something has happened in more recent times to modify materially this age-long stalemate of nations confronting each other. Perhaps the Mongols, weakened as a people by the loss of their best tribes and of their best lands north of the desert, and weakened as a state by the disintegration of their ancient empire, have become less watchful and jealous of their heritage. Perhaps, on the other hand, the Chinese have become more venturesome, emboldened by the pressure of their teeming millions and by the pact with Russia which gave them Inner Mongolia as a sphere of influence. It is possible that the world is now witnessing one of those transitional periods that have marked the rise and fall, the expansion and the elimination of competing peoples.

The return to Kalgan

Monday, September 18, the return journey was continued across this cultivated plain. Occasional outcrops of rock between mile 775 and mile 776 indicate that the ancient floor of complex rocks lies close beneath the trail, but for the longer stretches the simplicity of topography suggests that the underlying strata are sediments of later age.

The country is well watered; streams and small lakes are numerous, and roads are treacherous and heavy. Limestone fragments were found along

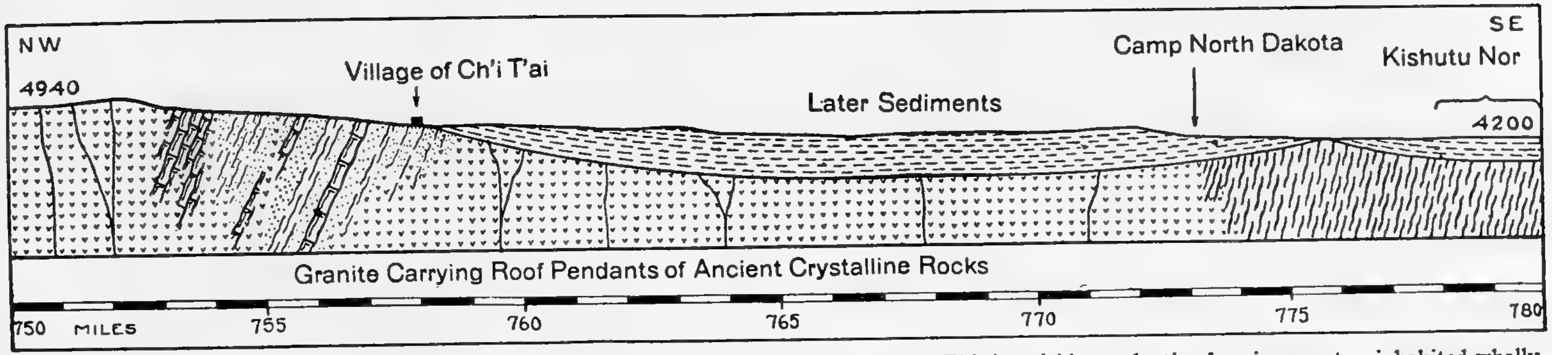


FIGURE 95.—From the granite bathylith to its sedimentary cover along the Kalgan trail. This is a richly productive farming country, inhabited wholly by Chinese settlers.

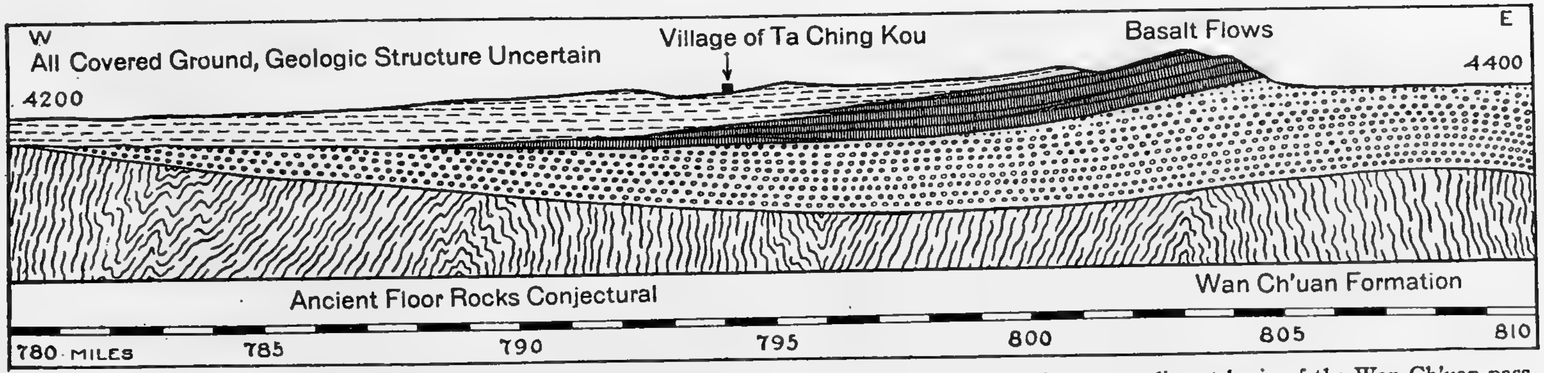


FIGURE 96.—Eastward toward the telegraph line, across farming country. The trail here enters the great sediment basin of the Wan Ch'uan pass (Compare with figure 5.)

the trail at mile 798 (Specimen 717, A.M. 10406), and basalts are exposed in prominent ridges from mile 800 to mile 804 (Fig. 96). This is probably the same series of basalt sheets or flows that is encountered in the edge of the escarpment at Wan Ch'uan Hsien Pass above Kalgan. From mile 805, the country clearly consists of sediments for some distance, and basalts are encountered again from mile 816 to the Great Wall (Fig. 97).

At mile 824, after following an easterly course for many miles—indeed for a whole day—we reached the main road and telegraph line leading to Kalgan, and the Expedition turned southward on the same route over which it had entered the Gobi region almost five months earlier. The night of the eighteenth was spent at the Chinese inn at Miao T'an, and the following day

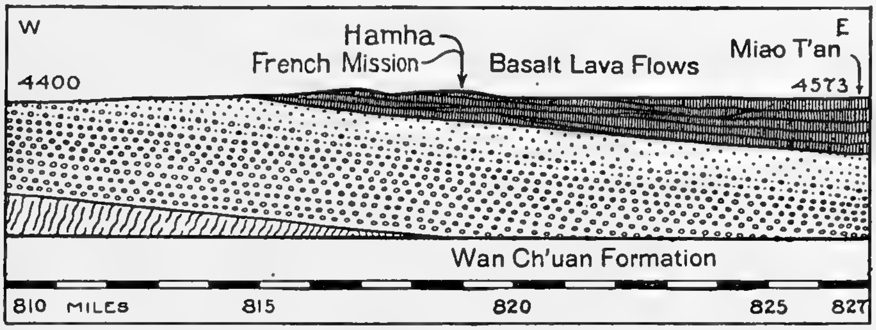


FIGURE 97.—End of the traverse of 1922. This section connects with the outward bound traverse at Miao T'an. (See figure 6.)

the return traverse was completed to Kalgan without further incident than the finding of extremely bad roads, much worse, indeed, than they had been in the spring when the journey was begun.

In the whole distance of more than three thousand miles, nowhere had there arisen conditions so difficult for travel as we now encountered on the Kalgan-Urga trail. More damage was done to the transportation equipment on this day's traverse, together with the first day out over the same ground, than was done over all of the remaining three thousand miles. The road for the last three days had been through cultivated country, where the transport of produce to market is one of the occupations of the people, and where long trains of carts pass daily from the upland country to the markets of Kalgan. In consequence of the heavy traffic and of the fact that no road is ever repaired, the trail is one vast stretch of interlacing ruts, with almost bottomless mud in the flat country, and with stones and bumps in the rugged country of the pass.

Finally, however, the journey was completed to the Anderson-Meyer compound in Kalgan without the loss of any of the transportation equipment. This was on September 19, five calendar months to a day from the time the party left Peking. In that interval the Third Asiatic Expedition had crossed the Gobi desert region of Mongolia twice, had traversed several hundred miles of northern border country, had covered more than three thousand miles of itinerary, had crossed the Altai Mountains, had made geologic, palæontologic, and zoölogic observations in considerable detail along the whole route, and had found several important fossil localities from which enough rare material was recovered to make the scientific reputation of the Expedition secure. On this reconnaissance a sufficient number of promising fields had been discovered and enough additional scientific work had been laid out to occupy years of further investigation.

PART III

SPECIAL LOCALITY STUDIES

PART III—SPECIAL AND LOCALITY STUDIES

INTRODUCTION

All the traverses of the Expedition, even those made under the most deliberate and favorable conditions, compelled rapid work and gave no opportunity whatever for detailed investigation. It was possible, however, to keep the run of the general geologic structure, as given in Part II of this volume, besides paying special attention to the selection of localities where it would be profitable to make a more extended examination. At three of the shorter stops, side traverses were made which proved to be especially helpful in gaining an understanding of the geology of the region. The side traverses are included in the itinerary account, Chapters III to X.

Wherever more time was available, the geologists made an areal study. In the course of the summer, several such places proved to be of exceptional interest, and these reconnaissance investigations were expanded as much as time permitted. The local studies constitute the chief basis for the statement of the systematic geology compiled by the Expedition. They are the key studies by means of which the fundamental structural and stratigraphic features were established.

Where the geologists made areal and structural studies of the rock formations, Mr. Granger conducted palæontological investigations and collected fossils. The two lines of research are correlated so as to tell a single story of the land and its inhabitants in successive periods. The detailed account of the palæontological researches is to appear in later volumes of this series.

In certain of the localities where time was available reconnaissance maps were made, showing topography and geology; they are the first of their kind for this part of central Asia. It is hoped that the local studies may furnish starting points for additional investigation and may be useful for comparisons, in the same manner as guide localities and standard sections are used in other countries.

Method of mapping

The maps of special areas were made with a Gurley mountain alidade and Johnson movement plane-table. A base line was measured in most cases with stadia, and this once accomplished, the stadia rod was but little used, for virtually the entire map was worked out by means of triangulation and vertical angle-readings. The Mongols have a most laudable custom of building stone-piles called obos, each stone of which is said to represent a

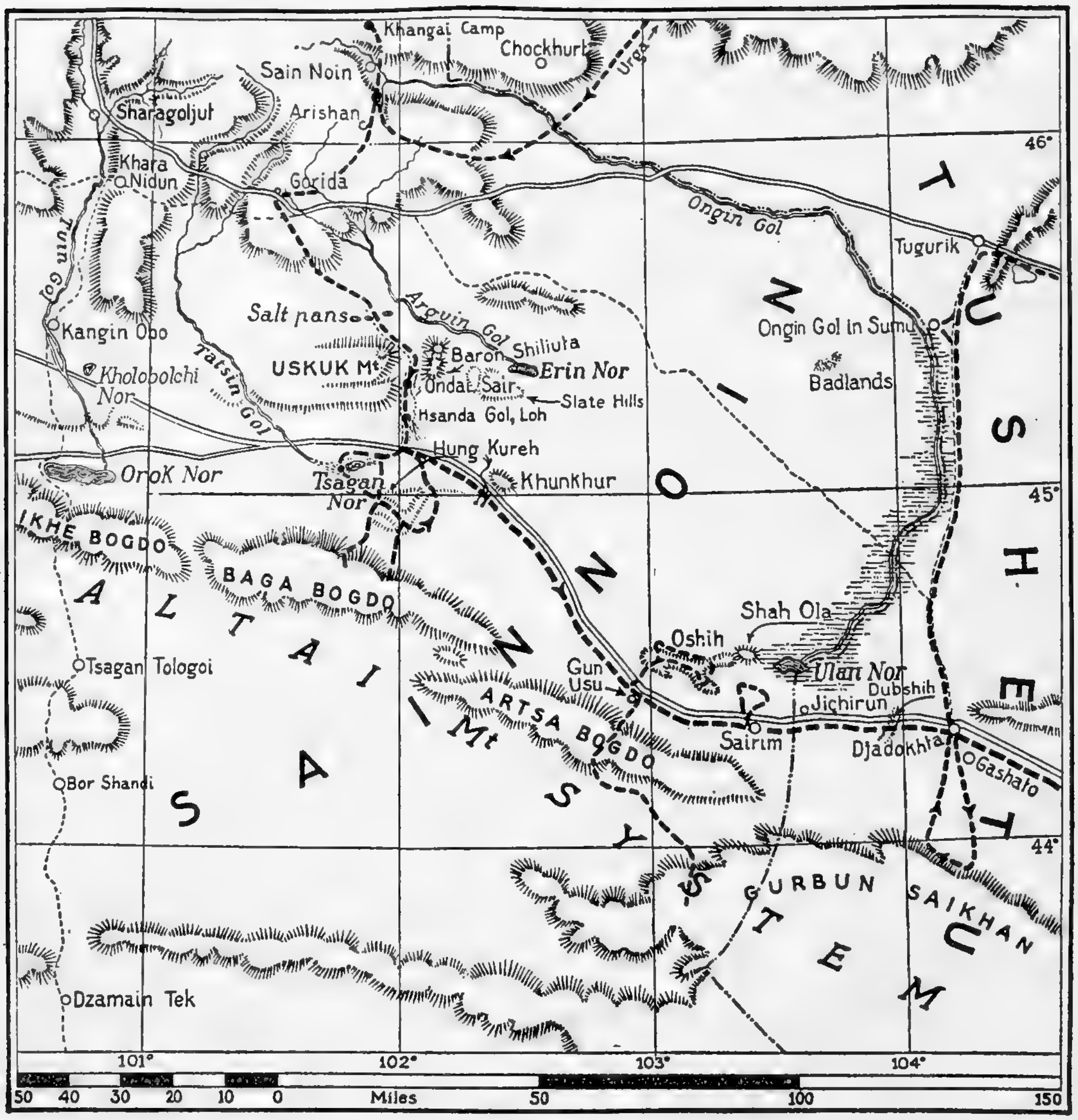


FIGURE 98.—Location map of the eastern Altai region. This sketch map shows the route of the reconnaissance, and the localities referred to in this report. Reconnaissance made since this map was drawn has shown that all the lakes except Orok Nor are intermittent.

prayer to Buddha. All important hilltops and many minor ones are crowned by obos, which enable the grateful topographer to locate points with a precision which in Christian countries would be impossible at this stage of the mapping program.

In special cases, where thickness of strata as well as topography was being recorded, the stadia rod again came into play, especially in the case of complexly folded rocks, where the precise location of all outcrops was necessary. In certain cases, where great speed of work was required, and where the nature of the ground permitted, the base line was run by means of a motor car. Several times in the course of such a run the car was stopped and the plane-table set up, so that the base line included a number of triangulation points in its length. Maps were surveyed on the scales of one inch to one mile and two inches to one mile, with contour intervals ranging from ten feet in the flat country about Iren Dabasu to one hundred feet in the mountains at the foot of the Altai. On the whole, a fifty-foot interval was found most practical for reconnaissance mapping.

The areas covered in this way by special maps total more than seven hundred square miles, and include the Iren Dabasu hollow, the Holy Mountain of Sain Noin, and the Uskuk-Tsagan Nor basin. Other studies in the list were made under conditions unfavorable to the making of a map, but such studies have yielded results which have helped materially toward an understanding of geologic structure, correlation, and origin. Five of these locality studies are covered in this report, as follows:

1. Iren Dabasu and Irdin Manha.
2. The Sacred Mountain of Sain Noin.
3. Uskuk Mountain and the Tsagan Nor Basin.
4. The Gurbun Saikhan.
5. Artsa Bogdo and Oshih.

Another chapter is added for the purpose of enumerating and discussing briefly other areas deserving additional exploration, and problems worthy of special study.

CHAPTER XI

IREN DABASU AND IRDIN MANHA

[Geologic Map, Plate XXIII, in pocket at end]

INTRODUCTION

After traveling many miles over almost perfectly level upland, the Expedition came, on the evening of April 24, 1922, to the edge of an escarpment, 255 miles out from Kalgan, from which one may look out across a basin-like depression. This is Iren Dabasu where the first important palæontological discoveries and the first studies of structural detail were made (Figs. 99 and 100).

In the lowest part of the hollow the ground water stands at the surface, and in rainy seasons there is a shallow lake which at other times dries up, leaving a crust of salt. The lake bed is soft and miry, but the surrounding lowland is firm ground. A little to one side of the trail are two wells from which caravans obtain the only water available for many miles. They mark, therefore, one of the established camping spots along the Urga trail. Here also is the telegraph station Erlien.

Four miles away, near the north margin of the depression, stands a small Buddhist temple, known as Boro Sunit (Plate XXIII). Aside from the operator of the telegraph station, a Chinese inn-keeper, and one or two Mongol families, there are no other inhabitants, for, though the place is less than two hundred miles distant from prosperous cultivated fields, here it is hopeless desert. There is a steady descent of more than two thousand feet from the edge of the Mongolian plateau at the head of the Wan Ch'uan Pass to this point, which lies in the lowest portion of the larger Gobi basin. The station is known as Erlien by the Chinese, and the saltpan is called Iren Dabasu by the Mongols. It is this latter name which has been adopted as a suitable designation for the whole local area and for one of the geological formations.

Our first discovery of fossils was made at the very lip of the hollow, where the geologists found teeth and bones of rhinocerotids in the yellow gravel capping the upland. But the most significant find was made the morning following our arrival at this camp. Fossils picked up by the chief geologist in the immediate vicinity of the camp proved to be dinosaur bones. With a little further search, the locality was found to be rich in these remains, and it was then decided to devote a week to more detailed study of the ground. Consequently the forces were divided, Mr. Andrews, with a part of the staff, proceeding toward Urga, while Messrs. Berkey, Granger, and Morris remained to carry on this work. Additional study proved that the locality was of even greater importance than had at first been supposed, and the stay lengthened beyond the original intention to about ten days, until the supplies were exhausted and we had to move or starve.

In the meantime, special attention was given to every phase of inspection and examination that could be carried out, and extensive collections were made. A map of the locality was prepared, the geologic column and structural details were worked out, and everyone turned a hand to collecting fossils from as wide a territory as was practicable. It was found advisable even to turn back along a part of the trail, to study the dissected bluffs noted twenty miles back, at mile 235, where sedimentary strata are exposed in even greater prominence than at Iren Dabasu. This is the Irdin Manha escarpment, where subsequently a very rare fossil fauna was discovered. Study of the Iren Dabasu locality, therefore, properly includes Irdin Manha. The strata exposed at the two places are intimately related; they belong to the same structural basin, which has had a long history. The problems of both spots are essentially the same, hence there is a distinct advantage in discussing the two localities together.

The geological complexity of the area was not at first apparent, and it was not until the fossil contents of the different strata were compared that the nature of the structural difficulties was appreciated. Structural relations in general are uncertain where so much of the ground is covered with a shifting mantle of sand, and where marked breaks in the succession of fossil forms correspond to very insignificant-looking unconformities in the stratigraphic succession. It was all the more important, therefore, to discover a key locality thus early in the expeditionary work, for similar conditions and obscurity of structural relations prevail in many other districts, and it is not likely that they could have been interpreted as rapidly, had it not been for the fortunate advantage furnished by the Iren Dabasu investigation. The geologists, therefore, look on this small depression of Iren Dabasu as one of the key localities of the Gobi region,—not only because it yielded the first dinosaur bones found in Central Asia, and because the Expedition's first announcement of scientific discovery was written at this camp (Granger and Berkey, 1922), but also because the geological studies made here became the criteria by which our reconnaissance was more rapidly conducted.

GENERAL ASPECT AND LARGER RELATIONS OF THE BASIN

In its broader lines, Iren Dabasu and Irdin Manha form a part of one of the largest sedimentary basins we have seen in Mongolia. The sediments

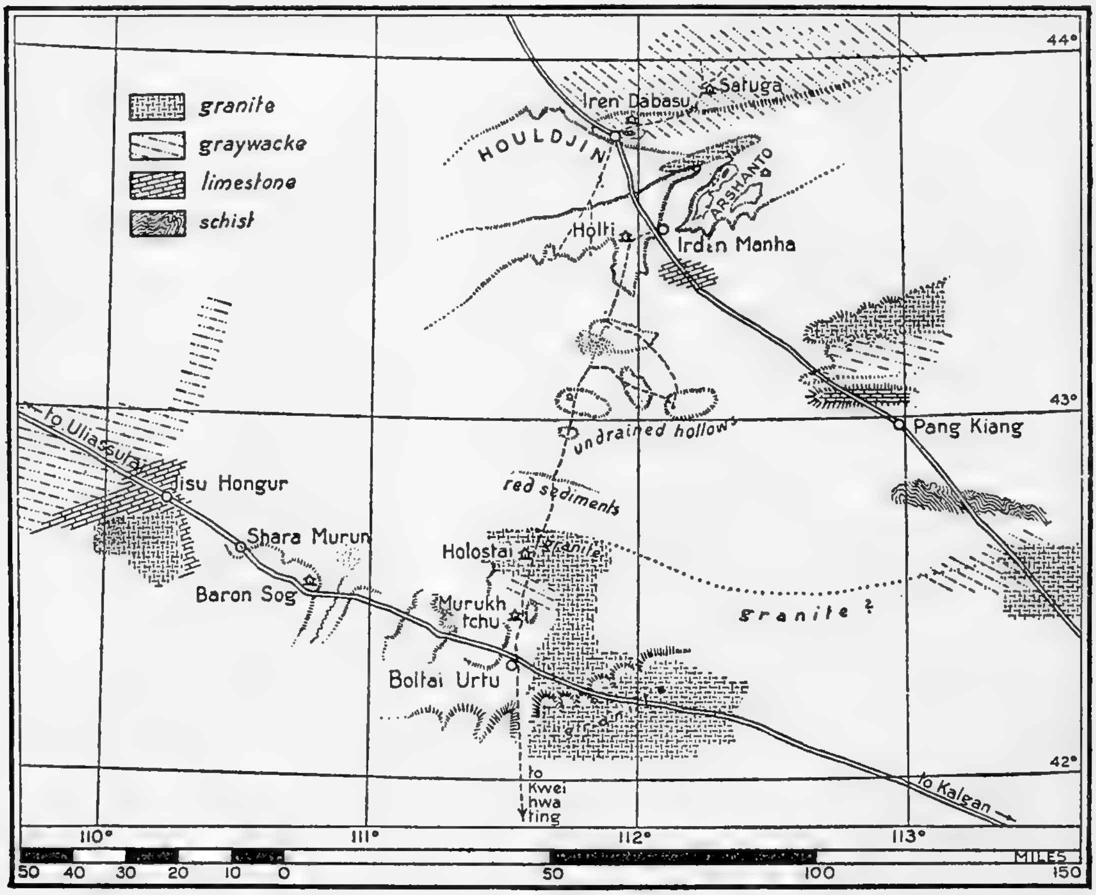


FIGURE 99.—Sketch map of the region between Iren Dabasu, Shara Murun and P'ang Kiang. Known areas of different major types of ancient floor rocks are shown by appropriate symbols, while the overlying later sediments along the several traverses are left blank, with the exception of a single limestone area just south of Irdin Manha, which is of fresh water origin and belongs to the later sediments.

are reached at mile 197 on the road from Kalgan, and there is no interruption of them until the slates appear at Iren Dabasu, mile 260. Along the Urga trail, therefore, from southeast to northwest the basin measures sixty-three miles in width. Toward the east, the basin has been followed for ten miles from the Irdin Manha bluff, without a glimpse, even in the distance, of a hard-rock wall terminating the sediments. Toward the west, the basin appears to be quite continuous with that of Shara Murun, nearly one hundred miles away. The width of the basin from north to south along the trail between Iren Dabasu and Boltai Urtu is at least seventy-five miles. The measurement would have been at least twenty miles greater if the trail had lain a dozen miles farther west. The total length of the basin in an east-west direction is not known; but the Shara Murun wing extends westward to Jisu Honguer, an approximate distance of ninety-seven miles west of Irdin Manha. If we allow only twenty miles for the continuation of the basin eastward from

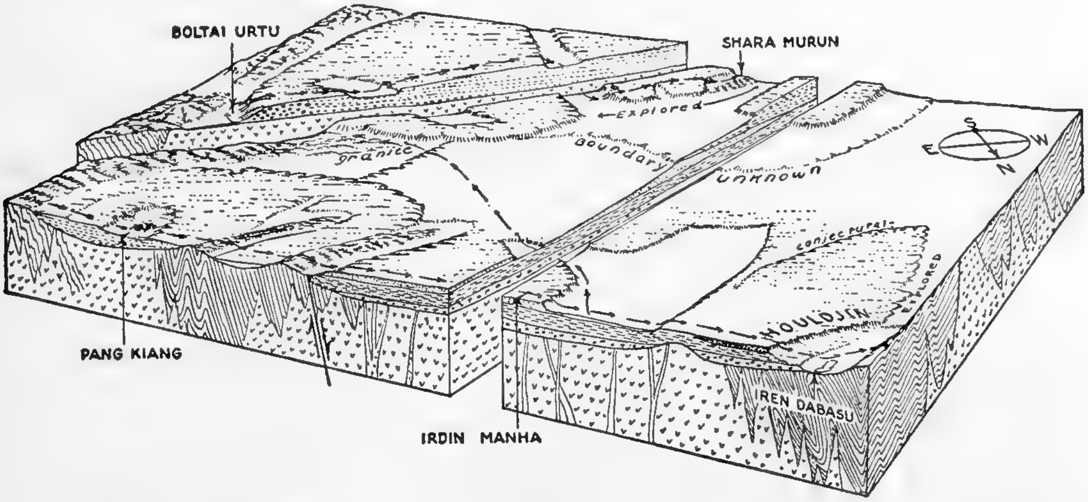


FIGURE 100.—Block diagram of the area between Iren Dabasu, Shara Murun, and P'ang Kiang. This shows the major physiographic features and the general underground structure of a part of southern Mongolia, approximately 100 by 125 miles in extent. The front edge runs northwestward and follows the Kalgan-Urga trail through the P'ang Kiang and Iren Dabasu basins. The rear diagonal cut shows the section between Boltai Urtu and Shara Murun, along the Kalgan-Uliassutai trail. The cut from front to rear illustrates one interpretation of the relations between the Irdin Manha and the Shara Murun formations, indicating that the Irdin Manha represents a lower horizon.

Irdin Manha, it still is more than one hundred miles long and averages more than fifty miles wide, with an area of nearly six thousand square miles (Fig. 99).

The area of our special study lies near the northern border of this large basin. It is bounded on the north by the hills of slate forming that part of the basin rim; on the south, our study did not extend beyond the scarp of sediments at Irdin Manha. Eastward and westward, the area examined by us had no definite boundaries.

There are three areas of oldrock in the vicinity—the slate hills on the north, a low ridge of granite on the east, and an exposure of graywackes and quartzites, thirteen miles south of Iren Dabasu. Remnants of the sediments are found clinging to the front of the slate hills, showing clearly that the sedimentary cover once extended entirely across the hollow in which the salt lake now lies. The floor of the lake lowland is part slate and part sediment. The strata of sand and clay form a low, irregular, much dissected scarp some distance south of the lake, and pass southward into a terrace about two miles broad. From the terrace the Houldjin bluff rises abruptly. It is a smooth-faced slope, dissected by short gullies, and at its top the level upland surface, covered by a thin mantle of gravel and drifting sand, extends southward for ten miles. Here the smooth upland is again broken by an immense

FIGURE 101.—The scarp at Irdin Manha. The field sketch shows the very level erosion upland, the short gullies of the cliff front, and a portion of a broad lowland belonging to the P'ang Kiang stage of dissection.

hollow, extending westward beyond the reach of vision. On the east and south, the hollow is bordered by a well-dissected bluff which we called the Irdin Manha escarpment (Figs. 101 and 102). Just at the angle of the scarp, where its north-south face swings around toward the west, there is a well called Jia Jing Shando, which Obruchev noted, more than thirty years ago, as a good camping place for those who would study the cliffs and their fossils.

As the names which we have used differ in important respects from those used by Obruchev, when he crossed this region in 1892, it will be well to pause at this point and compare the records of the two traverses.

Coming from the north, Obruchev passed Iren Dabasu, which he spelled Iren Dabassun Nor (Fig. 102). He ascended the scarp which our guides called Houldjin. He had no name for the bluff itself, but for the upland he records the name Kharangoin Tala (1900, I, pages 86–89). At Irdin Manha, he discovered fossils in a small butte near the well, Jia Jing Shando. He collected a fragment of a jaw which Suess (1899) later identified as *Rhinoceros* or *Aceratherium* and which he considered to be of Miocene age. Obruchev called the scarp Khuldyin-gobi—undoubtedly the same word as our Houldjin, which, we are told, applied to the scarp farther north. He called the plateau upland, south of the scarp, Irdin Mankha.

Because of the doubtful application of so many Mongol names, and because the names, as we applied them, have been used to define standard stratigraphic units, whereas Obruchev used them only as geographical terms to define localities, we have decided to retain the usage established in the papers already published. Professor Obruchev has courteously accepted this arrangement, saying:

"Your observations concerning the place of discovery of the Rhinoceros which I found in 1892 are wholly correct. I found it in the scarp of the plateau, Irdin Mankha, which my guides had called Khuldyin-gobi. My guides were Mongols who

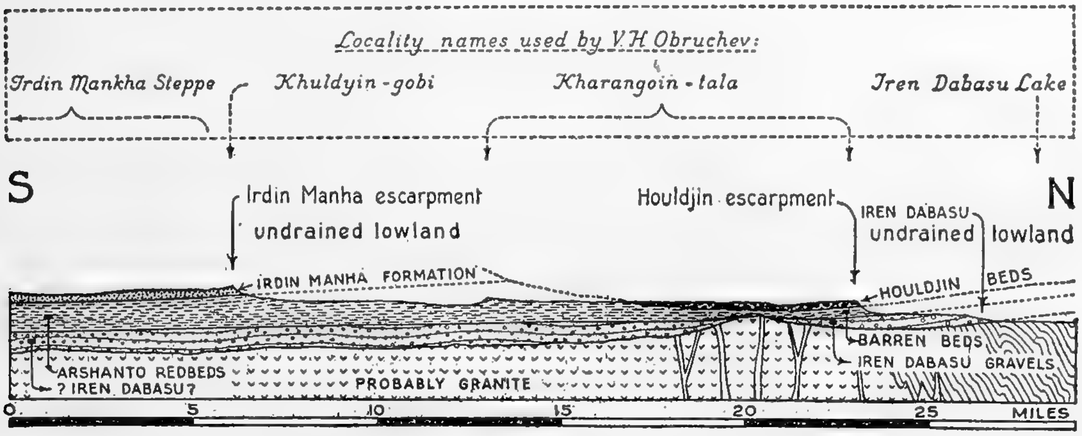


FIGURE 102.—Generalized geologic section between Iren Dabasu and Irdin Manha. The section shows at least three periods of basin making and three corresponding unconformities in this repeatedly warped basin. The unconformities lie (1) at the base of the Cretaceous Iren Dabasu beds, upon the uneven floor of crystalline rocks; (2) at the base of the Eocene Arshanto formation, upon the slightly disturbed and eroded Cretaceous beds; (3) at the base of the Oligocene Houldjin gravels, upon the eroded Eocene. Each unconformity implies a long period during which deformation was so gentle and erosion so slight as not to wholly remove the preceding thin deposits of sediments.

had traveled this road many times with tea caravans, so that they knew the road very well; but, of course, they could err very easily in the matter of exact names of localities. From your profile and my description of the journey, one must conclude that the rhinoceros tooth was laid in the Irdin Mankha formation and not in the Houldjin beds which are exposed much nearer to the lake, Iren Dabasu, and which I have briefly described on page 86 (1900, I), without having discovered any fossils in them."

Origin of the hollow at Iren Dabasu

The Iren Dabasu lowland is only eight miles wide along the Urga trail, but is more extensive east and west. The western scarp lies three miles beyond the telegraph station, while in an easterly direction the hollow extends for at least twenty miles. The lowland is not a basin structure at all, but is purely an erosion form, representing the P'ang Kiang stage of dissection referred to in Part II of this report, and discussed more fully in Chapter XIX. The depression is basin-like in topographic form, without outlet, and without very direct evidence of the process by which it has been made. The elongated depression has many of the features of a stream valley, and it is possible that a river started the excavation; but it is certain that the undrained hollow which contains the lake must have been scoured out by the wind. Here is a record of changing climatic conditions. Only when water was absent could the wind have excavated the lake bed. The presence of the lake tells of a return to rainier conditions than those prevailing when the wind was etching out the hollow, while the drying of the lake records a minor arid cycle.

There are many small stream courses, dry most of the year, leading from the bluffs toward the lake, and proving that both erosion and transportation are accomplished by running water. The fact that the stream courses do not lead out of the basin, and yet the basin does not fill, presents a problem that requires explanation. Even though there must be extensive movement of detritus, there is virtually no sediment accumulating in the bottom of the hollow itself. It is incredible that stream erosion could be a large factor in sculpturing the margins without corresponding sedimentary accumulation in the bottom, unless some other agent removes the deposits as fast as they can form. Only the wind could do it. The wind must be responsible for carrying away large quantities of loosened and transported material, so that accumulations are kept at a minimum.

The general effect is a depression of basin-like form, the margins of which, on the south side and around the west end, are formed by an escarpment of sedimentary strata, whereas the northern margin is formed by the stripped floor of complex ancient rock.

GENERAL ROCK STRUCTURE

In a very broad way, only two strikingly different classes of rocks are present—(a) metamorphic, of which slate is the commonest, representing the ancient floor, and (b) later sediments, mostly sandstones and silts, which constitute the nearly flat strata overlying this floor.

The rocks of the ancient floor are, we judge, of pre-Cambrian age. It is possible that they belong to the Nan K'ou series of China, but this cannot be determined in the Iren Dabasu locality. These slates carry numerous vein-quartz stringers and many dikes of igneous rock, some of which are trap or diabase, whereas others are granite. None of these intrusive units is of sufficient importance in the local study to warrant further description.

The sedimentary strata, which are of much more immediate interest, can be divided into three groups marked by differences in petrographic quality and in fossil content. The evidence indicates that the whole triple series is of inland continental origin. Part of the sediment was deposited in shallow lakes; much of it was laid down by streams with vigorous currents, and probably also a part is wind-blown dust and sand.

The Iren Dabasu formation

The first and oldest of the basin formations, to which the name of the locality was given, occupies the southern half of the hollow, where bare sandstone ledges form many outcrops (Fig. 103). With them are associated strata of fine clay, which are less resistant than the sandstones. The sandstones,—particularly the coarser varieties,—are cross-bedded and do not lie perfectly flat. The dip is always small, and its variation from place to place indicates slight deformation since the beds were laid down. These strata are much more indurated than are the overlying Tertiary beds, and some of the exposed layers are substantial enough to withstand the attack of weather fairly well,—so that they form projecting ledges, flat mesa-tops, and the caps of upstanding pillars. For the most part the clays are reddish or buff or slightly yellowish in color, and are comparatively thin-bedded. They vary from pebbly internal structure to extremely fine, almost silt-like material. There are a few lenticular, limy layers of very limited extent, one of which was found to carry fossil fresh-water bivalve shells. The principal constituent is quartz sand, and in composition there is no striking or unusual peculiarity. But certain beds carry such fine material that they might be called silts or even mud rocks, rather than sandstones. The finer silts also are simpler in general structure than are the coarser layers.

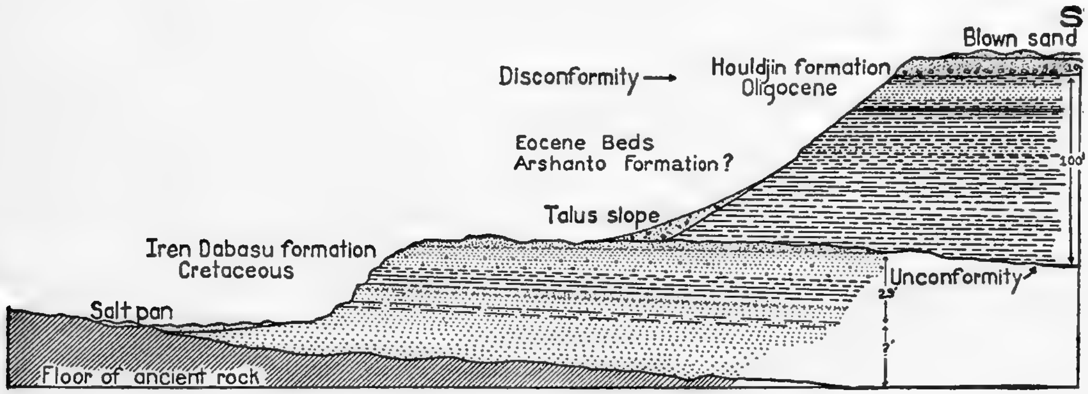


FIGURE 103.—The stratigraphic section at Iren Dabasu.

The only important differences, in addition to these petrographic variations, are presented by the fossil content. Certain beds carry multitudes of fossil fragments, and have yielded incomplete skeletons of several large dinosaurs. The formation proves to be of Cretaceous age. Only a remnant of the original deposit is left, and it is quite impossible to determine the original thickness. In 1923, a thicker deposit of Cretaceous beds was found several miles east of the lake (Plate XXIII). At least one hundred feet of sediment are exposed there, but only the uppermost thirty feet have as yet proved fossil-bearing. Sandstones are rather less abundant in the eastern exposures than in those west of the lake, but they are identical in character,—rather coarse, light gray sandstones consisting of angular grains of quartz with minor amounts of chalcedony, quartzite, feldspar, granite and epidote rock. The standstones are cross-bedded and bear only fragmentary fossils. The better fossils, especially the bones which were found associated in their skeletal positions, were found almost wholly in the beds of gray-green clay. One bed of red sandy clay, the highest fossil-bearing horizon yet found in the Iren Dabasu formation, contained numberless fragments of smooth, curving plates, which, it was thought in the field, might be the shells of dinosaur eggs. The discovery of perfect eggs at Djadokhta had not been made at that time, and these fragments were collected as doubtful material. An examination of thin sections under the microscope, however, has demonstrated that they are dinosaur egg-shells. The shells vary in size, and doubtless belong to several different types of dinosaur. The larger eggs are much bigger than those found at Djadokhta. Hence there are at least two places in central Asia where dinosaur eggs are found.

The list of fossils for the Iren Dabasu formation is as follows:

- Reptilia
  - Dinosauria
    - Predentata
      - Undetermined iguanodonts of various sizes and in great abundance
    - Theropoda
      - Numerous remains of struthiomimid and deinodont types.
  - Chelonia
    - Fragments of turtle bones.

Variegated Tertiary beds

The next overlying beds were at first believed to belong to the Iren Dabasu formation, but they are now known to belong to a different age and to overlie that formation unconformably. Obviously, therefore, the same name can not apply to these beds.

Everywhere the loose cover of wash conceals the transition from the sandstone ledges of the central part of the basin to the beds of an entirely different quality exposed on the marginal escarpment (Fig. 103). As nearly as can be determined, they lie flat and are less indurated than the Cretaceous strata. Some of the beds are better designated as silts or clays; most of them have a finely laminated parting, and would be classed as clay shales. They include a great range of color, varying from brick red to green and from yellow to blue. Some individual beds are variegated red, green, and drab.

In places the beds are concretionary, and there are a very few limy layers carrying septarian nodules. The most constant differences between these beds and the sandstone beds below are their less consolidated state, finer grain, higher color, less deformed condition, and their comparative barrenness. No fossils were found in them during the first season, but in 1923 a molar of a small lophiodont was found, together with great numbers of ostracods. The tooth, so far as it has been studied, is like those of the lophiodonts found in the Arshanto formation which will be described later. The stratigraphic position of the barren beds of Iren Dabasu agrees very well with that of the Arshanto, which is undoubtedly of Eocene age. At the base they pass beneath a cover that conceals their relation to the beds below; but it is now certain that between them and the dinosaur-bearing sandstones below there is an erosion unconformity which constitutes a floor for these much later sediments. A corresponding relation was proven later on with similar groups of strata in the Uskuk region.

The Houldjin formation

Upon the second series of beds described above lie about fifteen feet of yellow, pebbly gravel, which forms the top of the escarpment. The layer carries pebbles of quartzite, vein quartz, chalcedony, slate, and graywacke, and in both internal structure and fossil content is totally unlike any of the others thus far described. Even the fossils are but fragments and are distributed as if carried into place by currents. Many are well worn and rounded, and are more abundant in the coarse-grained, rusty basal part of the formation than in the higher levels. The deposit is of a rusty to buff color, but is not well cemented. Such partial cementing as there is readily breaks down under weathering, and the loose sands and gravels slump over the escarpment, where small streams distribute the débris over the lowland. Fossil fragments are found, therefore, scattered over the slopes across the lower formations, but are readily traced back to this layer as a source. The first bones found by the Expedition were obtained from this horizon, and here, too, the calcaneum of the giant hornless rhinoceros, *Baluchitherium*, and many other fragments were collected, giving the first hint of the presence of this huge mammal in central Asia. The following fossils have been collected from the Houldjin formation:

Mammalia
- Carnivora
  - Undetermined fragments
- Perissodactyla
  - *Baluchitherium* sp.

Mammalia—*Continued*
  Perissoda tyla—*Continued*
    Cadurcotherium sp.
    Cænopus or *Præaceratherium* sp.
  Artiodactyla
    Entelodon dirus, new species
Reptilia
  Chelonia
    Fragments of a large tortoise.

Apparently the Houldjin is a mere remnant of a once much more extensive formation, most of which has been completely removed by the processes that have made the Gobi plane. In spite of the fact that the formation cannot be traced on the upland, it is exposed again sixteen miles south of Iren Dabasu station, where the upland has been somewhat dissected, and where exactly the same relation of formations is found in the edge of a small depression. The drab clay is overlaid by a red clay, upon which rests a cap of rusty gravelly sand, which is undoubtedly the Houldjin. At that point the formation is about thirty to forty feet thick.

The sedimentary strata lying on the crystalline rock floor in the Iren Dabasu basin may be grouped into three formational units—(a) an older formation, chiefly of sandstones bearing dinosaur remains and, therefore, of Mesozoic age, (b) a clay formation, lying unconformably above, and clearly much younger, and (c) a topmost member, of sand and gravel, carrying a mammalian fauna, separated from the formation immediately below by another hiatus. The three distinct portions of the sedimentary column above the crystalline floor are represented in the accompanying columnar section in their approximate proportions (Fig. 103, page 203).

The Arshanto and Irdin Manha formations

Twenty miles south, at Irdin Manha, the Houldjin does not appear, and the escarpment is formed of Eocene strata. The beds can be divided into two groups,—one of red clays at the base, and the other of gray sandy clays, sands, and gravels above. There is a marked contrast between the two groups, and, while the name *Irdin Manha* formation was given to the entire sequence of red and gray sediments, it seemed well to reserve the possibility of separating the groups. Accordingly the name Arshanto was assigned tentatively to the lower red beds, while the name Irdin Manha was reserved for the upper gray formation. For clearness of reference these names will be used in describing the sediments, even if ultimately the Arshanto proves to be merely the lower Irdin Manha.

The Arshanto beds are prevailingly red clays and fine silts, which, on weathering, crumble into small hard chips. Much of the deposit is structureless, almost like loess; however, it lacks the vertical cleavage and the concretions so commonly noted in loess. In some places, a faint color-banding is seen in the red beds, but no shaly structure or marked bedding. Color-banding is held by Matthew (1915, pages 395–398) to be not inconsistent with wind deposits, and our own observations tend to support his opinion. In still other places, chocolate brown beds and, more rarely, thin gray layers appear among the red, and here at least there is definite bedding. About a mile east of Irdin Manha escarpment lies another broad, undrained hollow (Fig. 99, page 198), part of which is called Arshanto, from which the formation is named. Here some lens-shaped beds of gray and red sandstone were found in the red clays. A limited collection of small lophiodonts was made, which has not yet been fully studied; but the preliminary examination by Matthew and Granger shows that they are quite different from the lophiodonts of the Irdin Manha beds. The base of the red beds was not seen; the only bottom known for the formation is at Iren Dabasu, where it rests upon the Cretaceous beds. Whether there are Cretaceous beds beneath this part of the basin is not definitely known, but it seems probable that the Iren Dabasu formation extends farther south than is revealed in the outcrops around the lake.

The barren clays above the dinosaur beds at Iren Dabasu are distinctly shaly and well bedded; there is no doubt that they, at least, were laid down in water. They probably represent a different facies of deposition in Arshanto time, a local deposit in a shallow lake.

The Irdin Manha formation at the type locality consists of the prevailing gray beds of sandy clay, sand, and gravel. Some strata are mottled red and green; some few are even red; but there is a knife-sharp contact between the Arshanto and the overlying beds. The Irdin Manha is characterized by numberless channel-cuts and fillings, so that no individual bed can be traced very far. The quality of the beds also varies greatly, ranging from a sandy clay through sand and gravel. Some of the sand is exquisitely fine and uniform, and may well be a wind-borne deposit. Many of the beds of sand contain clay-galls, and some of the clays carry lumps of agglutinated sand grains. Most of the coarser sands are cross-bedded, with longer foreset beds than are seen in the Cretaceous sandstones at Iren Dabasu. The prevailing dip of the foreset beds is northward, suggesting accumulations from the south.

Two peculiarities of the Irdin Manha beds are especially notable. One is the presence of innumerable white marly or limy lumps, like concretions. In some cases at least, they show evidence of wear, as though they had been rolled along by water after they had become hardened. Possibly they represent limy concretions or fragments of lime-cemented sediments which later were broken up and washed out by the streams that laid the gravels and sands in which these lime-cemented lumps are found. The other peculiarity of the Irdin Manha formation is the lustrous polish of the pebbles found in it. Jasper, chalcedony, agate, quartz, and quartzite are brilliantly polished, while feldspar fragments are dull, save for the brightness of cleavage faces. The handsome lustrous stones have given the place its name, for Irdin Manha means "Valley of Gems."

Most of the fossils are rather fragmentary. There were no complete skeletons and no associated chains of vertebræ, though occasionally a manus or pes was found. For the most part, pieces of jaw, isolated teeth, or ends of limb bones make up the collection. Assiduous search revealed several fine skulls. The generally broken and scattered condition of the bones suggests that most of them were deposited by running water,—an inference which agrees well with the channel structures which are so common in the deposits.

The following fossils have been identified:

Mammalia
- Carnivora
  - *Paracynohyænodon morrisi* Matthew and Granger (1924*a*), new species of Hyænodontidæ
  - *Andrewsarchus mongoliensis* Osborn (1924*e*)
  - Mesonychids—genus and species undetermined
- Rodentia
  - Genus and species undetermined
- Insectivora
  - ? *Pantolestes*, or Pantolestidæ
- Perissodactyla
  - *Desmatotherium mongoliense* Osborn (1923*b*)
  - Lophiodonts, undescribed (Shara Murun and Irdin Manha)
  - *Protitanotherium* sp., undescribed
  - Titanotheres (dolicocephalic) undescribed (Shara Murun and Irdin Manha)
- Artiodactyla
  - Undetermined genus, Anthracotheriidæ
- Amblypoda
  - *Eudinoceras mongoliensis* Osborn (1924*d*)

In the season of 1923, the Expedition camped for two weeks at Iren Dabasu, and for three weeks at Irdin Manha, near the well Jia Jing Shando. The survey was extended in several directions, and our general knowledge of the region broadened. One observation that seems to be of especial interest is the very irregular distribution of fossils in the Irdin Manha formation. The camp lay in the midst of the richest deposit of fossils seen in this vicinity.

Northward, the bluffs were prospected all the way to the granite ridge and along its entire front, without disclosing any but scattered and fragmentary bones. Southward, the bluffs were followed for ten miles, but were for the most part barren. A traverse southward from Iren Dabasu reached the Irdin Manha escarpment at a point about ten miles west of the type locality, and here a considerable deposit of bones was found, but all were fragmentary and water-worn. At another place, some miles south of Holti temple (Fig. 99), President Osborn found a tooth of an amblypod, *Eudinoceras mongoliensis.* No locality in this part of the basin proved as rich as the first prospect, which, though we did not know it at the time, was the place where Obruchev, in 1892, had taken the first fossil recorded from Mongolia.

Shara Murun

Leaving Irdin Manha on June 12, 1923, the Expedition journeyed southward across seventy-five miles of unbroken basin country, finding Irdin Manha fossils at one place. The road leads through an area of granite and quartzite at Holostai temple (Fig. 99), but a splendid escarpment of sediment was visible some miles to the west, unmistakably resting upon the granite surface (Fig. 104). At Boltai Urtu the course turned westward and at once encoun-

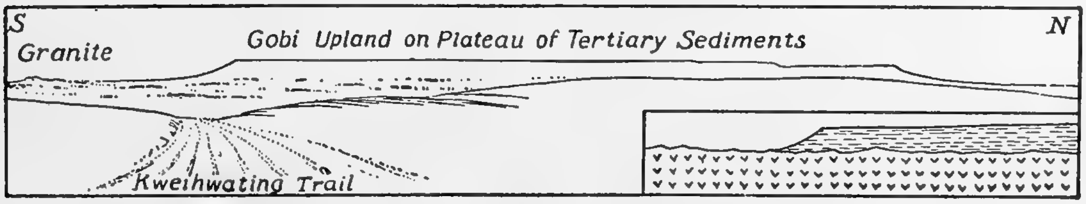


FIGURE 104.—The scarp at Holostai. The eroded surface of the granite is overlaid at the western end of the sketch by Tertiary sediments.

tered sediments, across which it continued for sixty-five miles to the Shara Murun district, where, in 1922, Mr. Granger had noted a rich deposit of fossils. Although so far away, Shara Murun is inseparable from Irdin Manha, and it carries a related, though distinctly later fauna.

A high bluff extends nearly east and west, and at the camp site is divided into two slopes, separated by a terrace nearly a mile wide (Plate XXII, B, page 183). The well near camp is called Ula Usu, which means "Mountain Water" or perhaps "Water on the Hill." Meanwhile a paper had been published (Berkey and Granger, 1923), using another name, Shara Murun, for this place, and the beds will therefore be called the Shara Murun formation, although the river Shara Murun actually lies sixteen miles east of the Ula Usu camp.

The upper part of the formation consists chiefly of white and light gray sandstones which are gravelly in places. Locally brownish and gray clayey beds appear in the upper member. The lower member is almost wholly sandy clay, richly variegated in color. Reds predominate, but there are purple, brown, and green layers, and some are mottled with many colors. The beds are lens-shaped, and some can be traced along the outcrop for as much as a mile. In some places, large crystals of gypsum are abundant, locally forming fibrous masses two feet long, and in one place beds of gypsum a foot thick were seen. No fossils were found where gypsum was plentiful.

Below the many-colored clays lies a hard red clay, which we named the Tukhum. It is nearly barren, but a few fossils were obtained which do not match those of the typical Shara Murun. Considering this difference in physical condition and faunal content, it seems probable that there is an older Eocene formation below the Shara Murun, in much the same stratigraphic position as the Arshanto occupies at Irdin Manha, but it is not yet possible to correlate the red Tukhum clays at Shara Murun definitely with the Arshanto.

The fossil field is extraordinarily rich, yielding not only numberless bones, jaws, and teeth, but several associated skeletons and many excellent skulls. From palæontologic evidence, it appears that the horizon is but a little higher than that of Irdin Manha.

AGE AND CORRELATION

At the time of the discovery of fossils in the Iren Dabasu, there was practically no basis for comparison between the strata found there and in other portions of the Gobi. Strata of similar appearance, but not yielding fossils, had been seen at several places on the journey, particularly at P'ang Kiang and at Irdin Manha, and it was conjectured that the beds of those localities are closely related to the sedimentary rocks at Iren Dabasu. When it was found, however, that certain beds of the Iren Dabasu district, including those at Irdin Manha, produced characteristic fossil faunas, it was possible in a general way to fix the age of those portions of the series. Thus it was evident that the dinosaur beds, found near the base of the geological column at Iren Dabasu, are of Cretaceous age. Nothing equivalent to them was known in central Asia. At that time it was supposed that the overlying beds of red and drab and variegated shales and sandstones belonged with them, and the whole combination was referred to at first as the Iren Dabasu formation. Subsequent work indicated much more clearly an unconformity between the dinosaur-bearing beds and the overlying, simpler, and barren strata. These were subsequently proven to be of Tertiary age, but in the Iren Dabasu basin, because of the lack of fossils, the exact horizon remained somewhat doubtful. East of Irdin Manha, a productive horizon in the barren-looking series yielded a primitive lophiodont fauna, indicating Eocene age. An effort was made to trace the connection between Irdin Manha and Iren Dabasu across the upland, but without much success. It is evident that the same general series continues; but whether the barren beds at Iren Dabasu lie above or below the lophiodont horizon is not yet clear. They are probably closely related beds, and are surely of Eocene age.

It is evident, therefore, that the Iren Dabasu formation, as revised, does not include quite as much as indicated in the original description (Granger and Berkey, 1922), and properly applies only to the Cretaceous sandstone beds below the unconformity. It is evident, also, that the overlying variegated barren beds of Iren Dabasu really belong to the same series as those found at Irdin Manha, and are very probably a part of the Arshanto formation.

At Iren Dabasu there is a disconformity separating the Arshanto from the Houldjin formation above, but the Houldjin beds do not appear at Irdin Manha (Fig. 102). The Houldjin formation carries a strikingly different fauna, indicating Lower Oligocene age. No higher fossil-bearing formations have developed at either place. Only a fraction of the original Houldjin formation remains beneath the Gobi erosion plane. The gravels and shifting sands on the smooth surface of the upland are recent. When these relations are plotted, it appears that there is no way of accounting for the peculiar distribution of the Houldjin formation, unless the region was warped subsequent to the production of the pre-Oligocene erosion surface. These relations are graphically indicated in the accompanying geologic cross-section (Fig. 102).

The total thickness of the sediments at Iren Dabasu is not more than two hundred feet, yet there are four plainly marked erosion and planation surfaces, as follows:

1. The floor of ancient rock on which all the sediments are laid down. This is the pre-Cretaceous peneplane and unconformity.

2. An undulating surface truncating and limiting the Cretaceous dinosaur-bearing beds. This is the pre-Tertiary unconformity.

3. An erosion surface separating the Arshanto formation from the Houldjin beds above. This is the pre-Oligocene erosion surface.

4. The present level upland, which also is clearly a product of erosion, we have called the Gobi erosion plane. On it rest only the drifting sands.

At Irdin Manha the erosion breaks are not visible, except the Gobi plane. The old floor is completely covered, as are the Cretaceous strata, while the pre-Oligocene plane must be warped to a position so high that it is actually above the present Irdin Manha surface, and has been completely destroyed by the beveling work of the Gobi planation.

Even the Gobi erosion plane is warped, as indicated by the elevation readings across the upland. Apparently this region has been for ages affected by gentle warping, with periods of deformation separated by periods of comparative stability. This kind of history has continued since the beginning of Cretaceous time, and the striking feature of it is the small total algebraic sum of plus or minus readjustment that has taken place. The alternating periods of deposition on the one hand and of distributive erosion on the other, each inaugurated and closed by slight deforming movements, are all comprised in this basin within present vertical limits of only two or three hundred feet of deposits.

It would be an error, of course, to assume that the present sedimentary column includes all the vertical movements which have affected the region, or that it contains all the sediments that were ever deposited there. Probably greater thicknesses have been removed from each of the formations than now remain, and if the total column could be reproduced and its erosion then accounted for to make the present structure, a much greater total vertical range would be covered.

The beds of the successive formations of later age often lie so nearly parallel that the actual physical break, caused by one of these erosion epochs, can rarely be seen. In the Iren Dabasu basin physical breaks were so obscure that two of them were not detected until a detailed study was made. When this was done, however, it was clear that the lowermost beds have been more deformed than those above, and in a few places slight angular unconformity can be measured. The deformation, however, has been too gentle to develop very pronounced structure, and in some cases the finding of a change in the fauna is the first suggestion of the presence of a physical break in the stratigraphic succession.

The evidence, as a whole, suggests a region of very gentle shifting of levels, the erosion work of one stage tending to destroy and remove from certain upwarped areas the deposits of the preceding stage. Then, after additional warping, the whole process is renewed, often with the directions reversed, and part of the deposits of the preceding epoch are removed from the newly uplifted area to the newly formed depressions. Thus, from one epoch to another these changes have taken place, with the result that there is an enormously complex interlocking and interweaving of formations, no single one extending continuously, or free from partial destructive erosion, for very great distances. The construction, therefore, of a complete geologic column for the Gobi will probably require correlation of all the scattered remnants of warped and eroded basin sediments in Mongolia. It may not be possible to formulate a complete column.

PLATE XXIV

PLATE XXIV.

THE SACRED MOUNTAIN OF ARISHAN.

(Painted by C. Lester Morgan after field sketch in crayons by Frederick K. Morris.)

CHAPTER XII

ARISHAN, THE SACRED MOUNTAIN OF SAIN NOIN

[Geologic Map of Arishan, Plate XXVI, in pocket at end]

INTRODUCTION

AFTER we had traveled more than a thousand miles and had gained a little confidence in our understanding of the geology of the region, we came one day, in the province of Sain Noin, to the vicinity of a strikingly majestic, black-browed, sharp-edged mountain, whose high-hanging, dark talus forms a frowning crown that seems to give it additional distinction (Plate XXIV and Fig. 105). Blocks of fallen rock in some places reach still farther down the mountainside and form a festooned fringe on its upper slopes, in sharp contrast with its own smooth base and with its simpler neighbors.

That it is an unusual mountain could be seen at once, but that it holds mystery and magic was still to be learned. Instinctively we felt that it must have a history somewhat different from anything we had yet seen. Later we were to find reasons for this and to learn why the locality is regarded with great veneration. At that moment we could not know that, for centuries past, generation after generation of men had respected this mountain, and that we were now in the presence of one of the natural wonders of their world, the Sacred Mountain of Sain Noin.

At the foot of the mountain stands a shrine, and a small group of yurts occupied by priests, among them a high priest, or Da Lama, who assumes charge of the place. He is a member of the official family descended from the Khans of Sain Noin, a relative of the ruling prince of a fourth of Mongolia. Apparently he considered himself directly responsible for the sacred place, representing in his own person both church and state, and carrying in his blood the pride of centuries of authority and privilege traced back to the golden age of the Mongol Empire.

Only a few feet from the lama's yurt runs a sparkling brook, whose waters, hot as the hand can bear, issue from the ground at the base of the shrine. These are the far-famed healing waters of Sain Noin, credited for ages with miraculous properties and bearing their own evidence of direct connection with supernatural powers. Else why do these waters issue forth hot, when the earth all around is frozen? Why, also, should they pour out in such abundance in a region where water is scarce at best, and where all other waters disappear into the ground? Even the mountain above stands frown-

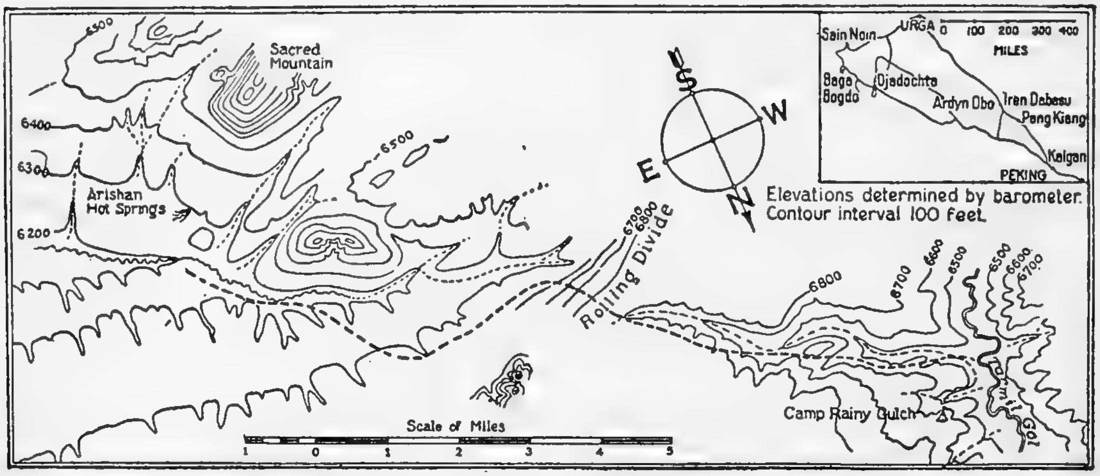


FIGURE 105.—Location map of the route between the Tarmil River and the Sacred Mountain of Arishan.

ing and threatening in a mutely protective way. Here is mystery. Here is result without adequate cause. Here the course of nature is reversed. What better sign could there be that this spot is to be revered more than other places? It must be that a god has touched the waters, or a benevolent demon dwells beneath, or the King of the World, whose realm lies in the earth below, has permitted this evidence of his power to mark the spot. Here is where the natural and the supernatural merge. It is a holy place!

Doubtless this mountain has been the object of pilgrimage through ages, and it must have looked down on many savage scenes as the sacred rites of primitive tribes were performed. So we liked to let our fancy spin the story of the Holy Mountain and clothe it with the superstitions of that early time, some of which still linger. Some of them, indeed, may come down from the long ago when primitive man stood for the first time awestruck before this evidence of hidden powers.

When we asked the Da Lama for permission to inspect the spring, take a sample of its waters, make a map of the district, visit the mountain, examine the formations of the locality, and study its geological history, he readily consented, but warned us, in a gentle though confident way, that nothing should be killed on this sacred ground (Plate XXV, A). The holy spot lost none of its charm for us because it happened to fit our purpose to study the mystery itself, for it is one of the type geological localities of northern Mongolia.

We found a great fracture in the earth's crust at the base of the mountain, and the strata have been displaced along it so that one side has dropped down several thousand feet. Taking advantage of this weakness, volcanic lavas have attempted to break through the fault zone, but their energy died out before much of an outbreak was accomplished. They came so near the surface, however, that even to-day one can find a few fragments of volcanic rock lying about on the ground, and probably there is much more below. Now, the rain that falls on the adjacent hills and sinks into the ground finds its way into the fractured zone, following along the hillside and under the valley till it encounters the lava below, which must still be hot. Heated by the lava, the waters rise of their own accord, issuing as hot springs.

Thus it has come about here, as so often elsewhere, that obscure and hidden geologic processes came to be interpreted in terms of mystery, and that natural forces, operating in full conformity with physical laws have been clothed with supernatural powers and have been ascribed to gods or demons not subject to law of any kind. These powers must be worshiped or consulted; at the very least, they must not be offended. And we heeded the serious-minded request of our priestly host not to kill anything here because "this is holy ground."

But we felt the strange spirit of the place—the sacred springs and the Sacred Mountain—and soon came to realize that here we were face to face with one of the primal elements of man's dawning wonder, respect, and superstition which together somehow seemed to involve the very rudiments of religion. Our physical explanation of the mystery and the Buddhist's worship of it were brought into clear contrast by the parting request of the lama prince. When asked what he would like to have us do for him or send him on our return to America, he said simply: "I wish you would send me an analysis of the water." To him it meant: "Tell me what makes this different from other waters—what has the King of the World done here?"

Race after race has dwelt here in the forgotten past, and each people has ascribed the hidden power to its own deity. Tribe after tribe has looked upon this place as one demanding reverence, recalling duties, warning the indolent of shortcomings, kindling aspiration in finer minds, and telling all of the presence of influences which they could not understand. For ages, god has succeeded god, each to inherit the magic springs from his vanishing predecessor. Buddha is only the latest of many masters. Each one has poured forth blessings at his pleasure, and called upon his people for sacrifice and for prayer, in accord with the custom of the day. It is a crude beginning of religion, but perhaps there is no other way to begin. One could stand before magnificent church edifices which have no greater charm and perhaps no wider influence than has this lone mountain of Sain Noin. One could listen to long sermons containing no more food for serious thought than the simple request of the Buddhist priest to be mindful of his holy ground.

FEATURES OF THE LOCALITY

Only a small area was included in our special study of this locality. The map covers about twenty-five square miles. It extends from one side of the valley to the other, just to the hill margins, and far enough on the south side to include the Sacred Mountain. The area covers a typical section of the local geology. The central portion is a smooth erosion surface, with gently rolling ground in which a stream with minor tributaries flows toward the southeast. At either side there is more pronounced hill country. On the whole, however, the topography is not especially striking. In certain places, the minor relief features indicate the structural attitude of gently dipping sedimentary beds, but elsewhere the topography is not particularly suggestive. The Sacred Mountain itself stands in marked relief, largely because of its cap of metamorphosed graywacke. The area has, however, a very complicated geological structure, with many faults and considerable variety of ancient crystalline rock, and with great thickness of sedimentary strata. Although the faults are of considerable magnitude they are wholly without topographic expression.

GEOLOGICAL FORMATIONS

Three important geological formations are represented, all in typical character (Plate XXVI). The oldest is the graywacke series; associated with it is a portion of the bathylithic granite, which is much younger. The most recent group consists of the Jurassic conglomerates and sandstones which occupy the central portion of the valley. The graywacke and granite form the valley sides. The only additional structural material is found in the dikes, which cut the granite and graywacke series.

Graywacke series

On the east side of the valley the graywacke series constitutes the bordering region for many miles. It is the chief formation of the Khangai mountain range, and we have called it the Khangai formation. In the Arishan locality its bedding is especially obscure, and it is neither as good a graywacke nor as good a slate as we find in some of the other localities farther to the east or to the south. It is grayish or greenish, dark-looking, clastic rock of the sandstone type, of very mixed composition. There has been considerable deformation, with development of cleavages and fractures that help to confuse the original structural habit of the rock. Enough of the bedding can be seen almost anywhere, however, to show that the formation stands steeply inclined, and that these hills are only the eroded remnants of a great series of mountain folds.

On the west side of the area, in the vicinity of the Sacred Mountain, there is a markedly different relation. The top of the mountain is capped with graywacke, as are also several other adjacent hills; but beneath the cap, and forming the base of the mountain with the adjacent ground, is granite. Erosion has cut down through the bathylithic roof represented by the remnants of graywacke formation, and has exposed and cut into the underlying granite. The granite magma had previously eaten its way up into the basal and down-folded portions of the graywacke series, destroying all the foundations on which that series had formerly rested. Thus there is here a splendid exhibit of the very roots of a roof-pendant (Plate XXV, B).

The capping graywacke has been cut and broken and somewhat metamorphosed. The granite, too, has been modified near the contact, for it has absorbed some of the cap-rock and has included fragments of it within its own substance. No place in the Gobi region shows these relations more clearly or to greater satisfaction for structural or historical study than the Sacred Mountain. The contrast between the graywacke and the granite is striking, and it is this change in quality of material, with almost black, metamorphosed graywacke forming the top of the mountain and furnishing the streaks of dark talus on its upper slopes, that gives the mountain its frowning appearance. The base is simple granite, weathering out to granular condition and pulverizing to fine sand that can be blown away. Even the granite is more readily destroyed than the graywacke which caps the hills.

The granite

The base of the Sacred Mountain and the adjacent hills, together with the ground sloping toward the hot springs, are all of a biotite granite. It is a massive type, of comparatively coarse composition, disintegrating in this climate somewhat more readily than the other rocks with which it is associated. The granite, therefore, is worn down in some places as low as the simple sandstones of Jurassic age which underlie the rest of the valley. There is otherwise nothing peculiar or unusual about it. The mountain stands so high wholly because it has been protected by the cap of relatively resistant metamorphic graywacke.

Near the hot springs the granite has broken into a multitude of massive blocks (Plate XVII A, page 143). They lie tumbled about in utmost confusion, and give at first the impression that they are the ruins of some great structure built by man. The same habit can be seen in many other places, always in low or wet spots, and we judge that the granite breaks up, by jointing, into large slabs which are dislodged by frost; and the rock in the low, wet places is more prominently affected in this way than the average rock, simply because the joints are more commonly filled with water, the freezing of which supplies the lifting energy. The blocks are then exposed to additional atmospheric attack, and at last disintegrate into arkosic sand which the wind can blow away. This is one of the steps, we judge, in the development of the peculiar depression-topography noted in most of the granite areas thus far seen in the Gobi region. Under the most favorable circumstances depressions of considerable depth are etched out.

The granite covers the whole western portion of the map, except for the remnants of the older graywacke which are part of the roof of the bathylith. Toward the east, however, the granite is limited at a definite line which proves to be a fault boundary. The formations on one side of the fault line are the granite and graywacke series, and on the other, the Jurassic sandstones and conglomerates.

The granite is intersected by many large dikes that trail off across-country, in wavy courses somewhat resembling the serpent-form dikes described in greater detail in the account of the Tsetsenwan country (Chapter V). These are of exactly the same type, only less pronounced in their serpent-form habit. They run somewhat more evenly, and are not quite so numerous as they are in the Tsetsenwan district. They vary in quality from granite porphyry to medium basic rocks, such as andesites; but their whole range of composition might easily come within the possibilities of differentiation in the granite bathylith itself, the same explanation applying to these as to the myriad dikes of Tsetsenwan (page 98). Some of the dikes break through the capping graywacke, and in such places tend to follow the structural lines of the rock.

Another feature, somewhat different in its meaning, is the presence of almost completely digested xenoliths of graywacke within the granite mass. In some places little is left to remind one of the graywacke substance, but there is a certain superimposed structural habit in the granite and it has a slightly different composition from the average, suggesting absorption of graywacke substance by the granite. In some places there are contact metamorphic minerals, such as tourmaline, which indicate local concentration of special constituents.

Thus the granite varies both in composition and in structure, especially as one approaches the cap of graywacke or the included xenoliths. In extreme cases the granite and the invaded rock may be so commingled that a given specimen consists of nearly equal parts of each kind of rock.

Besides the variation in quality due to absorption of the overlying rock,

PLATE XXV.

A. GUARDIANS OF THE SACRED MOUNTAIN.

The lama prince stands at the door of his yurt with attendant priests. The yurts and tents at one side belong to pilgrim visitors, and those in the middle background stand near the shrine and over the principal springs.

B. XENOLITH OF GRAYWACKE CAPPING A GRANITE HILL.

The black capping rock is graywacke metamorphosed by the bathylithic granite which surrounds it.

there is variety due to differentiation of the magma represented especially by the dikes (Specimen 251, A.M. 9940).

The Jurassic formation

In the middle of the valley the formation is wholly sandstone and conglomerate, which we have tentatively assigned to the Jurassic. The sediments are well-bedded and form a very thick series, terminated abruptly on the western margin along the fault line. Along this margin the beds are tilted so that one may walk across their upturned edges. Elsewhere in the valley they lie in various attitudes, for the most part much more nearly horizontal. Erosion of the tilted beds of varying hardness has produced many small hogbacks and cuestas. The rocks for the most part are thin-bedded and contain a surprisingly high proportion of quartz-sand. Sandstones prevail over all other types, and are associated with conglomeratic or pebbly beds, but shales are not developed to a great extent. It is not possible to tell the thickness of the formation, but several thousand feet of beds are actually exposed by the tilting of the strata. No fossils were found. Some very black, coaly-looking material was seen near the springs; this is regarded as equivalent to some of the coal layers found elsewhere in the Jurassic series (Specimens 252, 253, A.M. 9941, 9942).

Special products

The only unusual type of material found at Arishan consists of fragments of vesicular basalt. None was found strictly in place; all were scattered promiscuously in the vicinity of the hot springs. They are not especially attractive fragments, such as might have appealed to men who could carry them there as peculiar or fascinating pieces of rock, neither are they a part of the shrine. The one suggestive feature of their distribution is that they were found only along the precise line of the fault. The evidence favors the conclusion that they are residuary blocks from a formation that is in place. We believe that they represent a portion of a plug or outlet of volcanic material that at one time came up along the fault zone to at least the level of the present surface, and that they mark an incipient volcanic vent, which apparently did not fully develop. This, however, is not essentially different from the volcanic history of the area along the Ongin Gol at Sain Noin, where recent lavas have poured out and choked the stream (page 126). It is our opinion that the two volcanic outbursts are comparable in age and origin. The one at Arishan, however, did not succeed in furnishing a lava flow, as did that of Sain Noin, but followed the zone of weakness along the fault line almost to the surface. We are inclined, therefore, to assume a volcanic basalt plug in the fault at this point, and it is our belief that the hot springs owe their existence to this volcanic history and favorable structural relation (Specimen 254, A.M. 9943).

STRUCTURAL FEATURES

The Sacred Mountain area covers a portion of a down-dropped block—a typical structural feature of the Gobi region. The fault block extends north and south for at least ten miles and for a shorter distance east and west. Its margins are not simple lines, but, particularly in the vicinity of the hot springs, are formed of intersecting faults, enclosing angular blocks.

One cannot tell how much displacement there has been along these faults to bring the sandstones and conglomerates down against granite and graywacke. The strata are turned on edge for a long distance on the west side, and, from this alone, we would judge that the displacement was a large one, easily more than one thousand feet, but there is no other measure of it. The block, therefore, has the structural relation of a graben. There are faults on all sides, except, possibly, the north; and the dips are inward, showing drag effects along the north, east, and south margins.

There seems to be no way to determine with much precision the age of the faulting. It is a typical example of block-faulting, which is one of the characteristic modes of deformation in Mongolia, but the surprising thing is its limited size. The whole area of the block is not much more than twenty square miles. It is, therefore, a good example of the very moderate proportions of areas affected by vertical movement. In areas covered by the later sediments, the vertical movements commonly observed are simple warpings. But probably in the oldrock floor beneath, the faulted graben and horst are not rare.

Portions of at least two other down-faulted blocks were crossed in the Sain Noin district, within a traverse of twenty miles, and there must be literally scores of others in the general region. Some of the up-faulted blocks are great masses, such as form the individual Altai ranges, but a much greater number are small and much less conspicuous.

THE SPRING WATERS AND THEIR ORIGIN

The waters of the hot springs at Arishan reach a temperature of 127°F. as they issue from the ground. Although the ground is covered with a thin mantle of disintegrated rock and soil, there is no doubt of the position of the fault, on the exact line of which, as projected through this ground, the spring rises. For a short space the ground along the zone of the springs is richly carpeted with grass, but beyond that the barrenness of the desert reasserts itself.

The water itself is clear, tasteless, tinged with a slight bluish cast, and is not highly charged with mineral matter. One can detect the presence of slight amounts of H_2S, as the water issues from the ground, and bubbles of some other gas emerge—probably CO_2, but this could not be determined. No actual difference from pure water was detected by the gravitation method, both instruments reading 1,000 points. There is no mineral deposit, but the water feels smooth, almost soapy, and furnishes a delightful bath. There is scant opportunity for that, however; two or three small tents pitched over shallow excavations in the ground, where flat stones are laid on the edge of the excavation, furnish the sole equipment.

The same question of source is raised in this case, as with all hot springs. Are they meteoric or magmatic? Has the water entered the ground elsewhere as meteoric water and come up here, or is it pouring out from cooling or reacting volcanic sources beneath? In this case it is more reasonable, we believe, to hold that the water is of essentially local origin, particularly because of its purity. There is some question, of course, because of its content of gas, and it is probable that volcanic emanations of some sort join with it, even though its chief source is meteoric. We think that the waters are essentially meteoric, or local surface collections, which penetrate the ground and find their way into the fault zone. They can circulate more readily along the crushed rock of the fault zone than elsewhere, and tend to advance southeastward in the direction of a lower outlet. In their course, they come into contact with the still hot volcanic plug which represents the abortive attempt at eruption. We see no other adequate source of heat.

It is possible, of course, as far as the manner of issuing is concerned, for the springs to be of magmatic origin, but in that case one would surely expect a water of greater mineral content. The escaping gases favor a contribution from igneous sources, but even this is not a sound argument for magmatic source of the whole supply. Even meteoric water, which has circulated to considerable depth and reissues at the surface at a higher temperature, might give off bubbles because of the changed pressure conditions. But the presence of H_2S is more suspicious, especially as there appears to be a total lack of sulphides in all the rock formations of the locality. The H_2S may be derived from volcanic emanations.

In this connection, we recall that the basalt flow obstructing the Ongin River above the lamasery at Sain Noin, is so recent that the glazes of the glassy crusts are still preserved, and the stream has not yet accomplished dissection of it. The flow seems to have come up along a similar fault zone, at the edge of another down-faulted block. Probably the movement of the fault-block, as well as the outburst of lava, is dependent upon subterranean igneous activity.

At the surface, the commonest and plainest evidence is a lava flow, but the unseen escape of gases and the still more rare occurrence of hot springs may have the same meaning. Block-faulting and igneous activity are so commonly associated in the Gobi region as to indicate some vital genetic interrelation.

CHAPTER XIII

MOUNT USKUK AND THE TSAGAN NOR BASIN

[Geologic Maps, Plates XXVII, XXVIII, XXIX and XXX, in pocket at end]

On the traverse southward from Sain Noin to the Altai Mountains, the edge of a basin was reached in the vicinity of Mount Uskuk (Fig. 98, page 194). It was at once recognized as one of great promise for every phase of work in which the Expedition was engaged. The later sediments are splendidly exposed; many of the beds are fossil-bearing; and the total thickness accumulated in this basin is probably greater than in any other seen by us in the Gobi region. The major unconformity within the later sediments is very evident, and a series of deformation events, with their consequent structural features, is unusually well recorded. Surface features, also, characteristic of different physical conditions of the ground and different deforming and modifying processes, are clearly displayed here. The geologic story is carried with fewer breaks, through a greater range of time, and to later epochs, than anywhere else in Mongolia. This, therefore, proved to be a remarkably good locality for a special study; and the fact that all the other interests of the Expedition could be cared for there made it practicable to spend a longer time in the Uskuk-Tsagan Nor area than was devoted to all the other special localities together.

PRINCIPAL STRUCTURAL FEATURES

The major structural units are marked by prominent differences in physiographic features. The area is terminated on the south by the face of the great mountain, Baga Bogdo, one of the fault-block units of the Altai system (Plate XVIII, A, page 146, and Fig. 106). It is an upthrust mass of old pre-Cambrian metamorphic crystalline rock, undercut by bathylithic granite. Thirty miles to the north is another compound block of older rocks, thrust up sufficiently high to present rugged, mountainous topography (Plate XVII, B, page 143). This is the Mount Uskuk uplift. It is essentially a double fault-block, each half composed of pre-Cambrian crystallines of complex

FIGURE 106A.—Field sketch of the Baga Bogdo front. The skyline, which is about fifty miles long, represents the remarkably smooth Mongolian peneplane, beveling granites, schists, and graywackes. (Compare with figure 118, page 269.)

structure and very great petrographic variety, modified by intimate igneous injection of dominantly granitic material (Fig. 107). Within them, also are areas of conglomerates and sandstones of supposed Jurassic age, with accompanying brittle porphyries. The whole series, from ancient rocks to Jurassic beds, is closely folded, extensively deformed in every way, and much affected by deep seated volcanism. The mountainous units are bounded in all cases by faults and sharp flexures, and are surrounded by later sediments, which lie unconformably on an ancient floor of the same kinds of rock as are exposed in the mountain units (Plates XXVII and XXVIII in pocket).

Baga Bogdo, forming the southern border, and the Uskuk block near the northern border of the area, are the two great relief features. The lowland between them is covered with sediments and is structurally a basin, although it is not everywhere of basin form. An arch has been lifted across the original basin, so that now there are two basins—a small one just north of Uskuk at the extreme northerly margin of the map, with small saltpans in it; and a very large, open one lying between Uskuk and Baga Bogdo, with the lake, Tsagan Nor, occupying its lowest depression. Separating the two parts of the original basin, is the uplifted compound block of Mount Uskuk and the arch of sediments, with remnants of erosion in the form of lava-capped mesas that stand up as great landmarks not much less conspicuous than Uskuk Mountain itself (Figs. 108, 109). Indeed, Uskuk Mountain is capped with the same lava that caps the mesas (Fig. 110). Undoubtedly the lavas of the entire area once formed a single unit, of which only scattering remnants are now left to mark the position of a former continuous cover.

Principal interest in the basins attaches to the subdivisions, content, character, and correlation of the different sedimentary formations, which cover nine-tenths of the whole area. At Ondai Sair, on the easterly margin of Uskuk, it is plainly seen that there are two distinctly different series of strata, the lower one of which is more deformed than the upper, with an

FIGURE 106B.—Continuation of field sketch. The slope at the foot of the mountain is a series of alluvial fans, the oldest of which have been disturbed and eroded. Remnants of them appear as ridges partially buried in the younger fans, which are themselves trenched and partially refilled.

erosion break marking an unconformity between them. The beds beneath the unconformity carry an entirely different fauna from those above; the lower fauna is of Mesozoic, the upper of Tertiary age. A similar faunal difference was noted in the Iren Dabasu basin described in Chapter XI, but there the unconformity is not so plainly defined as at Ondai Sair, where it can be traced to actual contact. In both series of strata,—those below and those above the unconformity,—fossil faunas of definite scientific interest were recovered, and it is to these that one must turn for help in correlation. They indicate beds of Lower Cretaceous age at Ondai Sair and of Oligocene age at Loh, twelve miles farther to the south. At Loh, also, the palæontologists report the presence of a Miocene fauna, and twenty miles farther south, near Baga Bogdo, beds of Pliocene age were discovered.

THE ROCK FORMATIONS

The formations of the Uskuk locality may be grouped under two great divisions: first, the rocks of the ancient floor, represented by the upthrust fault blocks; and second, the division of later sediments which have been laid down on the more depressed portions of the ancient floor, and which have been preserved from subsequent erosion (Fig. 107). Chief interest attaches to the younger group, because of the advantages of extensive exposures, determinative fossil content, and relations that aid materially in unraveling their structure and in building up a dependable geologic column.

ROCKS OF THE ANCIENT FLOOR

The ancient rocks of the floor, although well exposed and exhibiting an unusually fine petrographic range, are not better developed here than elsewhere, and alone would not be as readily interpreted as those found in two or three other localities. They include the following units: (1) Ancient Crystalline Metamorphic Rocks; (2) The Graywacke Series; (3) The Bathylithic Granite; (4) Jurassic Strata; and (5) Post-Jurassic Intrusives.

These require brief additional descriptions.

The crystalline metamorphics

The major formations of the Uskuk block are crystalline metamorphics or injection products of them, folded sediments of less modified habit, and intrusives cutting the sedimentary members (Plates XXVII and XXVIII). The general effect is to produce ridges, extending in general east and west, with an average strike of about N.60°W. Virtually all the rocks with either schistose or bedded structure stand almost on edge. On the south side of the block the average direction of dip is to the north, and on the north side the average dip is to the south, as if the whole complicated series constituted a synclinal structure. The synclinal form is not simple, however, and perhaps the fold is not complete, since the same beds were not identified on the two limbs. On the whole, the metamorphics are simpler in the southern half than in the northern, and perhaps the difference in dip is due to relations of regional unconformity rather than to simple folding.

The series of formational members, in a traverse from south to north, is as follows: (1) intrusive porphyries; (2) Jurassic sandstones; (3) granite porphyry; (4) bedded rocks changed to schists; (5) crystalline limestones; (6) spotted gneisses; (7) mica schists; (8) sheared porphyry gneisses; (9) granite porphyry gneisses; (10) crystalline limestones; (11) gneisses; (12) crystalline limestones; (13) gneisses and schists with injections; (14) large crystalline limestone belt; (15) granite gneisses; (16) crystalline limestones and schists; (17) gneisses; (18) schists with many injections; (19) crystalline limestones and schists.

In this list, which is a generalized lithologic cross section of the southern Uskuk block, minor injection products and all intrusives except the major ones are neglected. One of the striking features is the abundance of limestones and schists. There are also extensive bodies of porphyries sheared into gneisses. Some of them are unusually fine examples of their kind, and mark a period of profound regional deformation. They are believed to represent one of the oldest series of rocks in the Gobi region.

The dominance of metamorphic rocks; the prominence of limestones and schists and shear gneisses; the abundance of injection phenomena of all kinds, from minute impregnation effects to large intrusions; the prominence of an east-west trend; and the commonness of faulting are the most characteristic structural features of the block. In spite of the confusing list of rock types, it is possible to group them into two fairly well-defined series. A portion of the column is made up chiefly of gneisses and schists; with minor silicated limestone members, all much modified from their original lithologic habit. We regard them as forming the more ancient portion of the complex. In contrast to these rocks it is possible to distinguish a series characterized by simple physical conditions. The members of the second series are crystalline also, but they have retained evidences of their original character more successfully than those of the other series. Limestones are present in larger proportion; schists and phyllitic rocks are more abundant; and quartzites are associated with them. They are strictly a series of ancient sediments but are probably much younger than the other series. There is, however, no other means of determining either their relative age or their correlation with the rocks of other regions. The simpler series may correspond to the Wu T'ai system as used in China, and the more complicated series may belong to the still older T'ai Shan complex. The thickness of all these rocks could not be determined, but each series must be represented by some thousands of feet.

The graywacke series

On the margins of the Uskuk block, and particularly in a second block of hill country some twelve miles east of Uskuk, there are extensive areas of slates and graywackes. The structural trend of the rocks carries them beneath the sediments of the Tsagan Nor basin; so it is certain that a portion of the floor of the basin is made up of rocks of this series. They are chiefly slates and graywackes with prominent bedding, much deformed by folding and some faulting, but not thoroughly recrystallized. The slates are fine-grained and slightly phyllitic, and the graywackes are granular, ranging from fine, almost slaty condition to conglomerate. Bedding is prominent, the trend of the folds is nearly east and west, and the series is of immense thickness. It is undoubtedly the same series as that noted along the Tola River and described in much greater detail on the traverse from Urga to Sain Noin (Chapters V and VI).

No determinable organic remains were found in the rocks, despite a very critical inspection for possible fossil content. The search yielded only some obscure tubular structures which may be borings or burrows, and some traces of unidentified minute forms which resembled algæ, but whose organic nature is inferred rather than proven. The lack of fossils in so great a formation of such simple structural condition is, we think, an argument in favor of its great age. We tentatively regard the whole series as pre-Cambrian, and as essentially the Mongolian equivalent of the Nan K'ou series of von Richthofen or the Sinian system of Grabau. This is one of the unsettled questions of the graywacke problem to which we hope to give more extended study.

Bathylithic granite

Large granitic intrusions with great variety of petrographic expression, are to be seen in the Uskuk block. It is not certain that all are of the same source, and probably they are of very different ages. Some of them, however, are of the type that has been designated on this Expedition, "the great Mongolian bathylith." The best, and by all means the most characteristic, exhibit is that forming the northern face of the Baga Bogdo mountain block. Here the oldrock floor has been thrust up to an elevation so great that the whole mountain front is made up of granite. The ancient crystallines and other formations which originally must have formed the roof of the granite mass, have been carried off by erosion, and the débris is now distributed as detritus with the strata that formed at its foot in the Tsagan Nor basin.

Jurassic strata

In our opinion there are in the Uskuk region no representatives of Palæozoic age. Between the graywacke series, which we consider to be late Proterozoic, and the sandstones and conglomerates with coal beds, which are probably of Jurassic age, the whole geologic column is a blank.

In the south margin of the Uskuk block, a thick series of sandstones and conglomerates stands on edge; with them there are thin, badly crushed coal beds of very poor quality (Plate XXVIII). The rocks are almost wholly non-fossiliferous, but there is no mistaking their general significance. They are simple, unmetamorphosed sediments, which are wholly of continental type. Most of the pebbles are quartz and quartzite; they are only moderately well bound together, and while certain beds are very substantial and hard, on the whole they are not strongly resistant to weathering. The conglomerate beds stand out better than the simpler sandstones. The series is closely folded, considerably faulted, and crushed. The total thickness could not be determined, as the whole series is cut off by porphyry eruptives, which form one margin of the area of Jurassic strata.

Post-Jurassic intrusives

In this area, as in many others, a very complex series of volcanic intrusive porphyries is associated with the Jurassic strata; and these together constitute the south margin of the Uskuk uplifted block. Most of the porphyries are of the usual brittle, fine-grained, or finely porphyritic type, varying from trachytic to andesitic composition, and, in rarer cases, to much coarser and more massive-looking granite porphyries. The granite porphyries form a larger part of the assemblage than was found elsewhere, but they are associated here with the Jurassic units. They are all somewhat deformed and are judged to be the youngest representatives of the floor on which the later sediments were laid down.

ROCKS OF THE SEDIMENTARY COVER

All the formations of critical importance in the Tsagan Nor basin belong to the so-called later sediments, which have accumulated unconformably on the erosion surface of the deformed, metamorphic strata and igneous masses of Jurassic and pre-Palæozoic age. The old, deformed masses will be referred to in the following discussion simply as the formations of the oldrock floor.

The strata lying above this floor fall into two definite series, separated by an unconformity (Fig. 107, page 229). The series beneath the unconformity, and occupying the interval between it and the oldrock floor, carries a

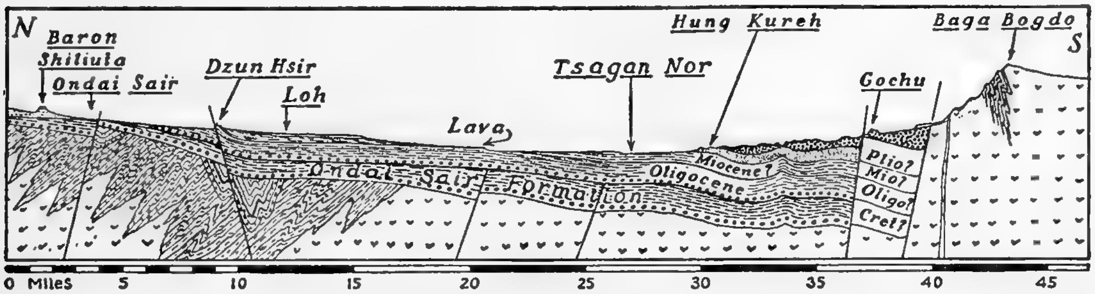


FIGURE 107.—Generalized geologic section across the Tsagan Nor basin. The figure shows that, in general, the sediments of the basin dip toward the Altai front, so that younger beds are encountered as one goes southward toward the Altai range. The formations of the oldrock floor are drawn approximately as they are found in the southern block of Mount Uskuk, just west of the section. Next above the oldrock floor lie the Ondai Sair beds, of Lower Cretaceous age, which were deformed and deeply eroded before the early Tertiary strata were laid down. These include a thick series of barren beds, at the base, and the Hsanda Gol beds, of known Oligocene age. The overlying Loh beds have been tentatively assigned to the Miocene. At Hung Kureh, the strata bear a late Pliocene fauna, and there is good reason for representing a physical break both above and below them. The rubbles of Gochu, regarded as early Pleistocene, were deformed and deeply eroded during Pleistocene time, and are partly covered by later alluvial fans.

fauna that indicates Lower Cretaceous age. Whether Upper Cretaceous beds are present under cover, or were at one time deposited in this region, is not known, but it is clear that there was considerable erosion of the lower series, and formerly there may easily have been a much greater thickness, representing younger beds that have been destroyed.

Above the unconformity there is a much more extensive series of sediments, which are all judged to be of Tertiary age. The lowest beds of this series are non-fossiliferous, and their exact position in the scale is, to this extent, doubtful; but they form a succession in which the higher strata, beginning with the Oligocene and closing with the Pliocene, are fossil-bearing. The series can be followed from bottom to top in a succession of exposures, continuous except for a long stretch of covered ground between the fossil-bearing beds of Pliocene age near Baga Bogdo and the beds of Miocene age at Loh. In that stretch, of course, the exact structural relations are lost. As far as can be seen, the strata appear to be conformable, and the succession might be essentially continuous, except for the overlapping which accompanied the repeated deformation of the basin. But the faunas which have been collected seem to indicate that there are breaks in the series, and that the sequence is not continuous, even though the gaps are physically inconspicuous in the field. If there is any break of greater physical consequence than elsewhere, it is that beneath the Pliocene beds, where the structural relations are not clear.

The uppermost series is limited at the top by a plane of erosion, parts of which are unusually smooth so that it bevels even the upturned edges of beds previously deformed (Fig. 111). No sediments of consequence have been deposited since that time, except along the immediate base of Baga Bogdo and, because of the fact that Pliocene strata are affected by this erosion, we infer that the erosion epoch belonged to Pleistocene time. Deformation followed, however, so that the planation surface is domed and warped, and the succeeding epoch is marked by a rejuvenation of stream work, which has accomplished extensive dissection. The only types of deposition noted above the erosion surfaces are: (a) very local stream wash, which is carried part way down the new trenches and is now being deposited along the lower reaches of the valleys (Plate XXXI, A); (b) alluvial fans on the margins of the uplifted mountain blocks, both Uskuk and Baga Bogdo; (c) wind-blown material, especially the sand dunes of the Tsagan Nor lowland (Plate XVIII, A, page 146, and Plate XXX in pocket).

The petrographic character of the strata forming the two greater series is, in each case, typical of the age represented, for similar characteristics have been noted in other districts. The older series, of Cretaceous age, is much the more hardened and substantial in exposed ledges, simpler in its coloring and more uniform in its bedding habit. The upper series is much the more variable; some of the beds are very highly colored; changes take place within a short distance, in thin layers, and some portions are strikingly variegated in color; the sediments are not hardened, and readily break down into sands, clays, and loams, so that there are no jutting ledges, and exposures are preserved only on actively eroding surfaces. The erosion history of the district, however, has favored the exposure of both series on a remarkably large scale in the Hsanda Gol valley, so that it is possible to examine an extensive succession of the beds in intimate detail.

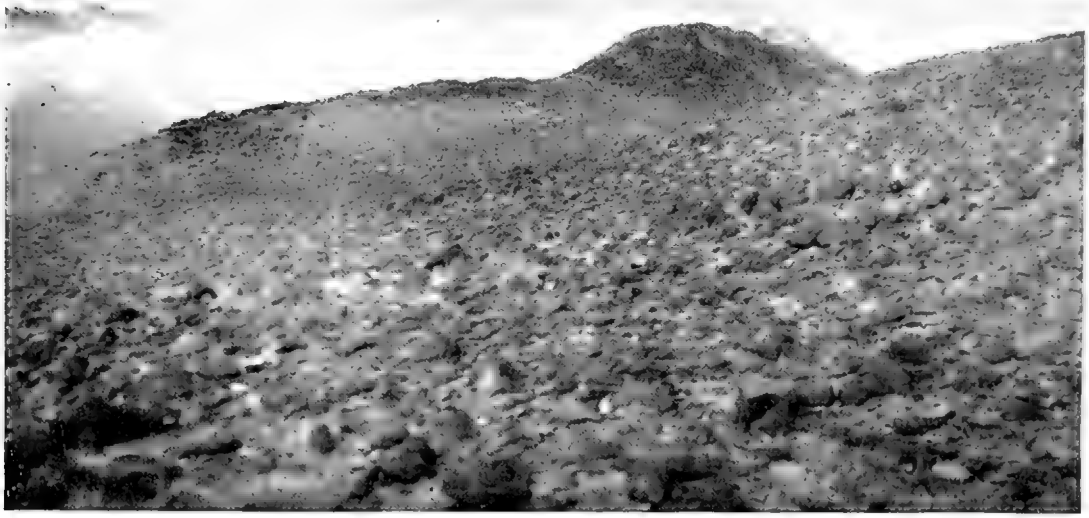
Cretaceous strata

The Cretaceous strata are chiefly gray, yellowish, or rusty sandstones, made up of quartz sand of uniform grain, extensively cross-bedded but not

PLATE XXXI.

A. THE HSANDA GOL.

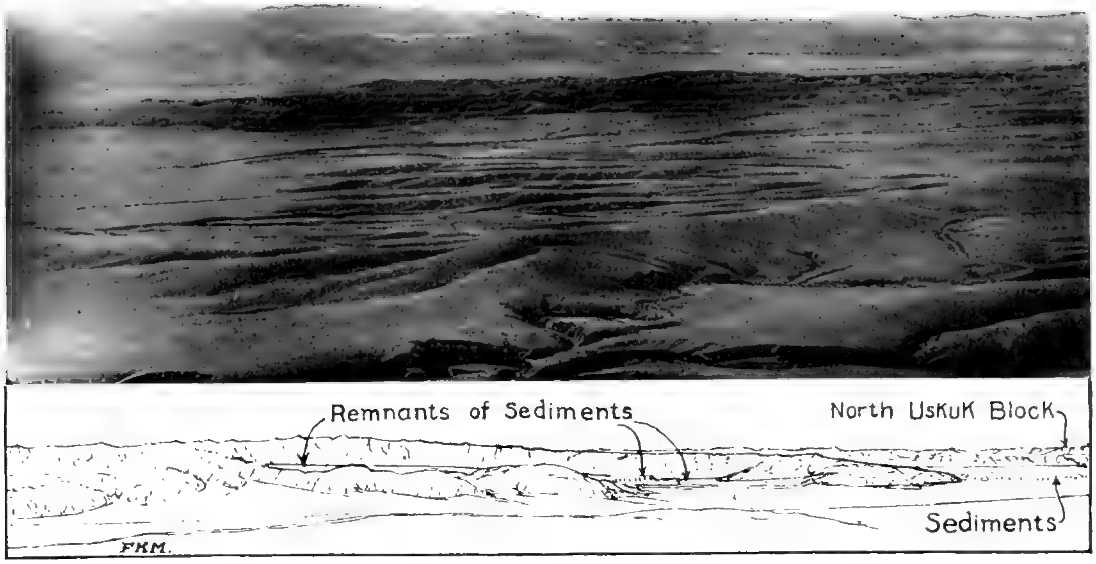
Lower Cretaceous and Tertiary sediments are exposed along this valley. The Gobi planation surface forms the skyline.



B. SOUTH USKUK BLOCK.

Along the southern margin of the south Uskuk block, tilted Tertiary lavas form a ridge, marking the flexure and fault that form the boundary of the Mount Uskuk uplift.

PLATE XXXII.



A. USKUK BLOCK FROM DZUN HSIR.

View westward from Dzun Hsir across the dissected Gobi surface, the adjacent red badlands, and the Hsanda Gol, into the south Uskuk block with its enclosed sedimentary remnants.

B. SEDIMENTARY REMNANT AT USKUK.

In the eastern end of the south Uskuk block, one of the sedimentary remnants is shown, surrounded by hills of the crystalline rocks.

strikingly pebbly or coarse. The sandstone beds alternate with thinner beds of drab shales and thin, black, perfectly fissile paper-shales. Together they form a very characteristic lithologic habit to which it is convenient to refer as the "sandstone and paper-shale series."

There are three places within the district where these strata are exposed: one in the angle between the two Uskuk blocks; another along the Hsanda Gol at Ondai Sair; and the third two or three miles farther to the southeast, where tilted strata of the same type, chiefly sandstones, are exposed. For convenience, the first two, which are connected in the field, are referred to jointly as the Ondai Sair locality. By far the best exhibit is obtained on the east side of the Hsanda Gol, where the strata can be traced eastward almost continuously from the edge of the fault-block to the unconformity at the top of the series. The succession from top to bottom is as follows:

Unconformity	Feet
1. Gray and purplish sandstones	6
2. Sands with greenish shaly layers	4
3. Cross-bedded sands with harder red layers	13
4. Rusty layer with white sandstone	5
5. White and gray sands with many shaly streaks	28
6. Paper-shales	4
7. Concretionary gray sand	3
8. Dark paper-shales	13
9. Indurated sandstone, dip southeast 16 degrees	2
10. Sandstone with many dark paper-shale layers	7
11. Paper-shales	5
12. Hard sandstone layer	1
13. Yellowish and rusty, cross-bedded, pebbly sandstone	7
14. Dark paper-shales	6
15. Strongly bedded and indurated sandstone	2
16. Yellowish and white sandstone layers	17
17. Paper-shales	2
18. Cross-bedded white sandstone	3
19. Coarse, nodular sandstone layer	1
20. Thick series of paper-shales, and thin, drab, sandy shales with many thin, sandy layers	39
21. Strongly indurated sandstone layer	1
22. Dark paper-shales with interbedded sands	20
23. Strongly indurated sandstone	1
24. Paper-shales with sandy layers	5
25. Indurated sandstone, dipping southeast 10 degrees	1
26. Dark paper-shales	10
27. Strong sandstone layer	1½

		Feet
28.	A series of drab and gray paper-shales with associated sandy layers	21
29.	Dark-colored paper-shales	4
30.	Rusty sandstone bed	2
31.	Dark-colored paper-shales	2
32.	White, fine sandstone	5
33.	Yellow sandstone with thin, drab layers	5
34.	Drab-colored shales and paper-shales	6
35.	White sandstone with occasional shaly layers	20
36.	Drab shale	5
37.	White sandstone	5
38.	Dark paper-shale	3
39.	White cross-bedded sandstone	9
40.	Sandstone, with more uniform structure	10
41.	Gray shales	5
42.	Dark shales with thin paper-shale and white sands	6
43.	White sandstone	5
44.	Drab and yellowish shale layer	2
45.	Yellow and white sandstone	10
46.	Paper-shale	2
47.	Yellow sandstone	5
48.	Covered ground, undoubtedly underlaid chiefly by sandstones to the river level, estimated	50 ±

The base of the section was not reached, and the top of the section has been cut off by erosion. The striking point about the series is the alternation of simple sandstone beds with sharply defined and finely developed fissile shales of the paper-shale type.

A summary of this detailed column gives a total exposed thickness of 390 feet. The difference in elevation between the exposed base and the top is 215 feet. In the total there are twenty-nine definite sandstone beds, and nineteen thin shale or paper-shale layers. The sandstones total approximately 230 feet, and the shales or mud rocks, 160 feet. The typical paper-shales amount to nearly 100 feet. This section offers one of the best exhibits in variety of Cretaceous strata found in the Gobi region. We found a larger number of paper-shale beds at Ondai Sair than in all other districts put together. Beds of Cretaceous age elsewhere are dominantly sandstones, such as those at Oshih and Djadokhta; but the paper-shale type is found again at Oshih (Chapter XV, page 271), and on the Urga trail north of Iren Dabasu (Chapter IV, page 63).

Fossil content.—Although the formation is not highly fossiliferous throughout, there are many beds which carry fossils. The paper-shales are the most prolific, but not all of them contain fossils. Some of the forms are new, but a fauna which is in part identical with it has been reported from eastern Siberia. The fossils have been reviewed by Professor Cockerell (1924). The complete list thus far identified is as follows:

Reptilia
Protiguanodon mongoliense Osborn (1923*d*, 1924*a*).
Large sauropod undetermined.

Pisces
Lycoptera middendorffi Johannes Müller. Exceedingly abundant in the paper-shales. The specimens agree with *L. middendorffi* in the proportions of the fins, rather than with *L. sinensis* A. S. Woodward, from the lower Jurassic (?) of the Province of Shantung, China. These fishes are discussed more fully in a later contribution (Cockerell, 1925); they form a new family, Lycopteridæ, apparently ancestral to the Cyprinidæ, and have scales scarcely differing from those of the European minnow.

Crustacea
Estheria middendorffi T. R. Jones, 1862. Exceedingly abundant in the paper-shales (Pl. II, fig. 2).

Insecta
Ephemeropsis trisetalis Eichwald (1864)
Ephemeropsis melanurus Cockerell (1924)
Cymatophlebia (?) *mongolica* Cockerell (1924)
Trichopterella torta Cockerell (1924)
Indusia reisi Cockerell (1924)
Chironomopsis gobiensis Cockerell (1924)
Coleoptera, spp. incert.

Plants
Baiera furcata (Lindley and Hutton)
Phyllocladites (?) *morrisi* Cockerell (1924)
Czekanowskia sp.
Equisetaceæ (?) fragments.

Tertiary strata

Above the unconformity representing an old erosion surface on the deformed Cretaceous strata, there is a series of younger beds several thousand feet thick. It is not possible to measure the total thickness accurately, but certain portions of the series may be measured in detail. These portions include a great succession of beds near the bottom, a small section near the middle, and a somewhat larger section toward the top. All are undoubtedly of Tertiary age, but the horizons marked by definite faunal content fall within the Pliocene at the top of the series, and within the Miocene and Oligocene near the middle. It is assumed that the lower beds, three thousand feet of which lie beneath these determined horizons, may reach down into the Eocene, but definite determinations of such horizons have not been made in this area.

Fossil content.—The fossil content of the upper sections is listed below:

1. Oligocene strata along the Hsanda Gol at Loh, which we have called the Hsanda Gol formation.

Mammalia

Carnivora

Hyænodon pervagus Matthew and Granger (1924*a*)
Didymoconus colgatei Matthew and Granger (1924*a*)
Didymoconus berkeyi Matthew and Granger (1924*a*)
Amphicticeps shackelfordi Matthew and Granger (1924*a*)
Bunælurus ulysses Matthew and Granger (1924*a*)
Bunælurus parvulus Matthew and Granger (1924*a*)
Palæoprionodon gracilis Matthew and Granger (1924*a*)
?Cynodictis elegans Matthew and Granger (1924*a*)
?Cynodon (Pachycynodon) teilhardi Matthew and Granger (1924*a*)
?Viverravus constans Matthew and Granger (1924*a*)

Glires

Tsaganomys altaicus Matthew and Granger (1923*c*)
Cyclomylus lohensis Matthew and Granger (1923*c*)
Cricetops dormitor Matthew and Granger (1923*d*)
Selenomys mimicus Matthew and Granger (1923*d*)
Tataromys plicidens Matthew and Granger (1923*d*)
Tataromys sigmodon Matthew and Granger (1923*d*)
Karakoromys decessus Matthew and Granger (1923*d*)
?Prosciurus lohiculus Matthew and Granger (1923*d*)
Eumys asiaticus Matthew and Granger (1923*d*)
Desmatolagus gobiensis Matthew and Granger (1923*d*)
Desmatolagus robustus Matthew and Granger (1923*d*)

Insectivora

Tupaiodon morrisi Matthew and Granger (1924*b*)
?Tupaiodon minutus Matthew and Granger (1924*b*)
Palæoscaptor acridens Matthew and Granger (1924*b*)
Palæoscaptor rectus Matthew and Granger (1924*b*)

Perissodactyla

Baluchitherium grangeri Osborn (1923*d*)
?Epiaceratherium sp. Matthew and Granger (1924*b*)

Artiodactyla

Eumeryx culminis Matthew and Granger (1924*b*)

Batrachia

Pelobatidæ

Macropelobatis osborni Noble (1924)

2. Miocene strata at Loh

Mammalia

- Rhinocerotidæ
  - *Baluchitherium mongoliense* Osborn (1924g)
- Mastodontidæ
  - *Serridentinus mongoliensis* Osborn (1924g)

3. Pliocene strata at Hung Kureh, at the foot of Baga Bogdo

Mammalia

- Artiodactyla
  - Large cervid
  - *Gazella* sp.
  - *Camelus* (?)
- Perissodactyla
  - *Hipparion* sp.
  - Rhinocerid
- Proboscidea
  - Mastodont
- Rodentia
  - *Castor* sp.

Aves

- *Struthiolithus*
- Fragments of a smaller bird

Recently Mr. Granger has come to believe that the ostrich and perhaps the mastodon are of Pleistocene age, and that they come from beds that overlie the typical Hung Kureh formation.

The whole series of beds is undoubtedly of continental type, including stream wash, lake sediments and wind-blown material. The quality ranges from loose, poorly bound conglomerate or pebbly sands, to simple, massive sands and marls and loamy clays. The colors vary from white to brilliant reds and dull greens, and many beds are variegated. Changes in quality are sharply marked, bedding is a prominent feature, and most of the thicker beds show marked change of quality. All are poorly indurated and weather down readily, so that the slopes are covered with loosened débris which conceals the beds beneath. Only in exceptional positions along the stream courses and in the badland patches, are the beds well exposed. Wherever erosion is comparatively rapid, as it is in the softer beds exposed on the east side of the Hsanda Gol near Black Butte, the strata are well exposed and are carved into badland topography. Midway in the series are basaltic lavas and tuff beds, which formerly covered a large portion of this area and doubtless were connected with the more extensive beds of lava still covering the upland country farther to the west. Above the lavas, similar variable sands and loamy clays of brilliant colors continue. Higher in the series, especially in the Pliocene beds of Hung Kureh, the colors are softened—many of the beds are almost pure white or slightly yellowish—the bedding becomes less regular, and finally pebble beds are interlayered, doubtless representing alluvial fan extensions from the Baga Bogdo uplift. The upper pebble beds may mark the limit of the Pliocene.

The whole series can be regarded as a large unit with three rather distinct physical divisions. The first division begins at the Cretaceous unconformity and includes the lower portion of the series along the Hsanda Gol, up to the lava beds. The second division begins with the beds above the lavas, and includes the strata exposed through the district of Loh to the valley of Tsagan Nor, beyond which beds of a different quality appear. The third division includes the lighter colored beds of Hung Kureh. Roughly, this division marks the most prominent physical breaks and in a general way corresponds to the faunal changes. The beds of the lower division are essentially barren, though Oliogocene fossils are found just below the lava sheet; the middle division carries a lower Middle Oliogocene and a Lower Miocene fauna; and the upper division is of late Pliocene age. There is, however, no noticeable physical break corresponding exactly with the Oliogocene-Miocene hiatus.

Clearer understanding of the character of the strata constituting this Tertiary series can be secured by referring to the detail at points where sections are best exposed. The best exposure for the lower division is that in the vicinity of the Black Butte, called Dzun Hsir by the Mongols, where a total thickness of more than two thousand five hundred feet of sediments is exposed along a stream course which cuts across the upturned edges of these beds. Here the whole series is flexed as it merges into the fault bordering the south side of the Uskuk block, and is planed off by Pleistocene erosion.

At this point the unconformity at the base is not exposed, but the conglomeratic beds, which are recognized everywhere as forming the lowest layers, are exposed, and undoubtedly the basal member is at no great depth beneath them. The succession from bottom to top in the Dzun Hsir section is as follows:

1. Yellowish conglomerate, with reddish sand streaks	41
2. Red sandy bed	2
3. Heavy yellowish conglomerate	88
4. Green sandy layer.	1
5. Heavy yellowish conglomerate	18
6. Red sandy layer	1
7. Heavy yellowish conglomerate	86
8. Red sandy bed	4

9.	Heavy conglomerate	86
10.	Succession of red beds	40
11.	Heavy conglomerate	35
12.	Red and buff layers	43
13.	Coarse white sand	5
14.	Deep red bed	25
15.	White conglomeratic rock	60
16.	Red checker stratum	13
17.	Coarse conglomerate	14
18.	Variegated pebbly layer	2
19.	Conglomerate bed with red and green layers	35
20.	Red and white and drab alternating beds	222
21.	Pebbly, white and red, variegated beds, with drab layers	155
22.	Red beds, with many alternating white layers	115
23.	Conglomeratic white and red beds	51
24.	Succession of red and white alternating beds	90
25.	Dominantly white beds, with reddish layers	233
26.	Series of red and white alternating beds	60
27.	Red and white variegated beds	80
28.	Alternating red and white beds	48
29.	White pebbly conglomerate, with pink sandstone layers	45
30.	White, gravelly sand	63
31.	Buff and orange and light red beds	100
32.	Brown-colored stratum	50
33.	White, coarse sandstone	35
34.	Succession of drab and white sand and silts in 5-foot layers	110
35.	White and reddish sands and gravel beds	196
36.	Hardened white sandstone stratum	50
37.	Variegated beds	50
38.	Drab-colored and white layers	30
39.	Buff sandstone layer	3
40.	White sandy layer	10
41.	Deep red stratum	70
42.	Tuff or ash bed	14
43.	Bottom flow of basalt	64
44.	Top flow of basalt	218

In this long succession of beds, which, even in this statement, is generalized so that some of the details represented by the section itself are merged into groups, it is possible to make three—or possibly four—major divisions, characterized by dominance of certain lithologic qualities.

(1). The bottom group is represented by a dominance of yellowish conglomerates and conglomeratic sands. The beds lying immediately above are also prevailingly conglomeratic, but have a larger intermixture of fine-grained layers and a greater proportion of reddish colors. These two groups, which together represent a total thickness of about 400 feet, form the conglomeratic base of the column.

(2). Above the conglomerates there is a complex series of alternating beds of sand, loamy silts, and clayey or marly material—with a generally variegated aspect, ranging through every shade of color from white to black, from deep red to pink, and from brown to yellow, with the reds predominating in the general color scheme. In places where there is badland erosion, the dominance of reds is so strong that it creates a striking scenic effect, and when seen from a distance, in the slanting rays of the sun, these dissected areas become what we called them—"the flaming badlands of the Hsanda Gol" (Plate XXXII, A). The type of sediment with dominantly high colors continues from the conglomerate beds of the bottom group to the tuffs and basalts that form the top, and measures a total thickness of more than 2,000 feet.

(3). The last group is made up of tuffs and basalts, with a total thickness of nearly 300 feet.

The total thickness, measured along the course of the stream where the section was made, amounts to 2,761 feet after correction for dips. This can not be taken as quite accurate, however, for there is a slight additional correction to be made because the section does not lie exactly normal to the strike of the beds. This would reduce the total thickness as exposed to perhaps 2,600 feet, but the bottom is incomplete, and there are minor variations in dip, introducing additional errors. The best that can be said, therefore, is that the section includes more than 2,600 feet of sediments including 300 feet of volcanic material.

The dips vary from almost flat to vertical; the lowest beds, which are exposed in the northern end of the section, are the least disturbed, and the successive layers increase in dip until the central portion of the variegated beds is reached, where many of the strata are vertical. From this point on, the dips gradually diminish, until the capping basalt is reached, where there is a dip of 48 degrees.

Former extent of later sediments

Later sediments of Cretaceous and Tertiary age occupy the basin country around Mount Uskuk, and thence southward to Baga Bogdo. Nowhere in this basin portion does the oldrock floor come to the surface, and it is quite certain that in the deeper portion it must lie beneath several thousand feet of later sediments (Fig. 107). Certain features of the mountain blocks of north and south Uskuk, as well as of Baga Bogdo itself, lead one to believe that at one time sediments of similar type may have covered even these areas, and that their present relief, as well as their ruggedness, is due to uplift, stripping, and further erosion. The features supporting this view are:

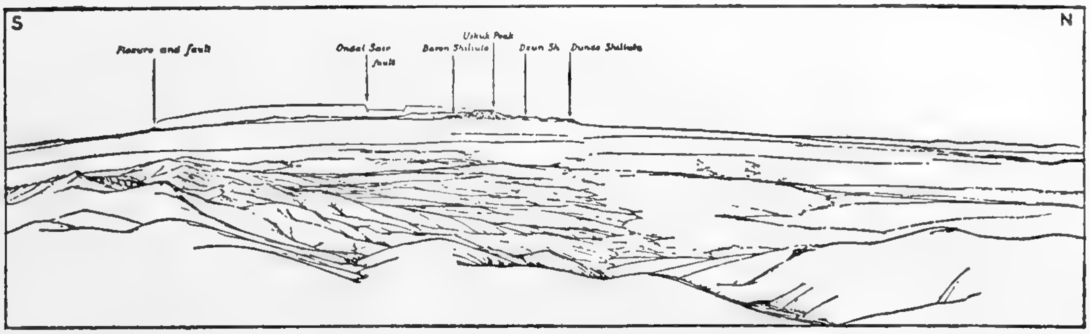


FIGURE 108.—Domed and dissected planation surface of the Mount Uskuk area. This is a clearly marked example of recent doming of a small area. Mid-Tertiary sediments have been strongly flexed and faulted. In early Pleistocene time erosion developed an almost perfect plane which, still more recently, has been arched and redissected. Both the sediments and the oldrock floor exposed in the background record the deformation.

(a) The faulted margins of the blocks, (b) The presence of remnants of sediments within the blocks, (c) Remnants of a similar basalt cap on Mount Uskuk and on adjacent sedimentary strata, (d) The evidence of planation.

Evidence of the faulted margins.—Wherever the facts could be determined, there is faulting along the margin of the blocks, and it is this faulting that disturbs the bedding of the later sediments adjacent to these margins. Everywhere remnants of these strata are dragged up so that the nature of the displacement, as well as some approximation to its age, can be determined. On the south side of Mount Uskuk block, for example, there is a sharp flexure against which the sediments stand on edge, and great thicknesses are cut out (Plate XXIX, Plate XXXI, B, and Fig. 107). The total displacement along this flexure must measure more than 2,000 feet. The strata involved, although not very narrowly determined, are at least of mid-Tertiary age. On that side, therefore, the deformation which has given some, if not all, of the present relief to the Uskuk block is as late as mid-Tertiary. Along every margin where the detail can be seen, such displacements are noticeable; but it is not everywhere that the age of deformation can be traced to so late a stage. At the foot of Baga Bogdo, strata of late Pliocene age are disturbed, indicating that part of the uplift is post-Pliocene.

Evidence of the sedimentary remnants.—At several places within the Uskuk blocks there are remnants of later sedimentary strata on the unevenly eroded crystalline floor, still preserved from the erosion that has increased the present relief (Plates XXVIII and XXXII). Some of the remnants lie in rather elevated positions, the most westerly one attaining an elevation quite comparable to portions of the adjacent blocks themselves. It is very evident, with such relations, that they are no more than remnants, left from the stripping of a very much more extensively covered area; it is entirely probable, indeed, that the sediments at one time covered every bit of the crystalline areas now exposed, even to the tops of the highest mountains. What the original relief of the floor beneath was like is not so easily determined, but it is clear, from the pocket-like distribution of some of the remnants of sediments, that it was uneven in the Uskuk area.

The upland portions of the Uskuk blocks fall fairly well into peneplane form, which seems to have prevailed much more extensively in the beginning of basin history. The sediment remnants, however, lie below the upland

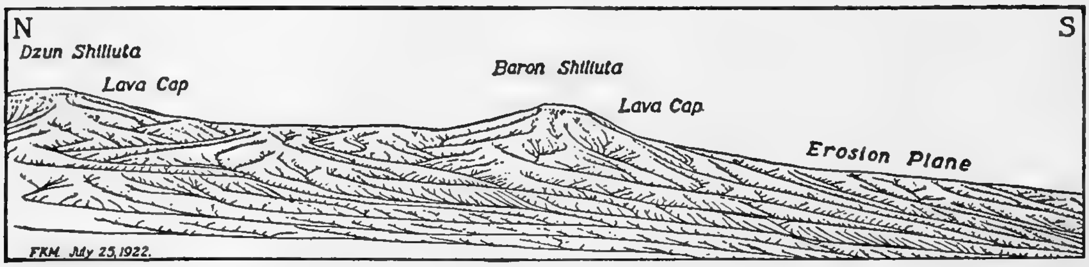


FIGURE 109.—Field sketch of Baron Shiliuta. The lava-capped mesa of Tertiary sediments stands east of Mount Uskuk. The gullies are all tributary to the Hsanda Gol. The dissection is subsequent to the planation epoch marked by the Gobi erosion surface. (Compare with figure 108.)

levels, in pocket-like or trough-like depressions (Plate XXXII). The simplest explanation, perhaps, is that the peneplaned Uskuk area was uplifted and dissected in some earlier time, possibly in the Upper Cretaceous; and then it was covered with sediments again, so that the inequalities of that new erosion surface were filled. Subsequently, the area was once more differentially uplifted and has been stripped, with the preservation of only a few patches of the sediments in what remains of the deeper valleys belonging to the earlier dissection.

In support of this hypothesis, we may cite a rather striking example of retained sediments in the south Uskuk block, where it is very clear that they occupy a valley (Plate XXVIII). In later redissection a stream course was laid out in much the same form, passing down this valley, with an outlet at one time near the southeast corner of the block. At the present time the drainage from this section is all toward the northeast, and the valley with its sediments is abruptly terminated against a wall of crystalline floor rock, which now rears across its course. It is reasonably clear that the abrupt termination of the valley against the wall is caused by faulting, but the evidence is not clear as to when the faulting took place. It must have taken place, either during the downwarping which subjected it to sedimentation, or, more likely, during the later upwarping which preceded the present stripping. The valley is an ancient one, and belongs to a previous erosion epoch quite as prominent as the one now in progress. The present form is due to the reexcavation of the ancient valley down to the point where the fault was discovered. There the course was blocked, and the stream has found an outlet across the north side of the valley and through the ancient crystallines. It is evident, therefore, that the original peneplaned block was deeply dissected before the sediments were laid down, and that the new streams of the present day are redissecting both the ancient block and the pocketed remnants of its cover. Perhaps the earlier dissection corresponds to the Cretaceous unconformity, but of this there can be no conclusive proof until the age of the sediments can be established.

Evidence of basalt remnants.—The highest mountain in the Uskuk blocks is Mount Uskuk itself, which stands as a prominent landmark, capped by more than a hundred feet of basalt (Plate XXVII and Fig. 108). None of the other nearby peaks or upland portions of crystalline rocks is thus capped with lava, but farther to the west, within easy range of vision, we saw extensive continuations of lava fields, which are doubtless of the same age, and probably once belonged to the same unit. However, with the exception of Mount Uskuk itself and the three mesas, all portions of the uplifted areas are stripped of lava. It seems to us entirely allowable to postulate their former connection, thus assuming that in former times these lava remnants were continuous, covering not only the three mesas and Mount Uskuk, but many scores of square miles beside. Since that time the Mount Uskuk block has been reexcavated, and the southern block has been completely stripped. At the time of the basalt flows, the area, including most of the Uskuk block, must have been covered with sediments, because the same basalts in the vicinity are known to be both underlaid and overlaid by Tertiary sediments.

Basalt flows of the same type form small remnants in the basin far to the northeast and in the saltpan basin immediately north of Mount Uskuk, but here they are at a level hundreds of feet lower. If these basalts are related, there must have been a great amount of warping and faulting since they were poured out, and this inference is supported by all the structural evidence. On the south side of the Uskuk blocks, the basalts stand on edge along a sharp flexure or fault, and thus complete the picture of a great area of sediments capped by basalt, which has been deformed by the upthrust of the twin blocks of Uskuk (Plates XXVII and XXVIII). The subsequent period of erosion has been long enough to transform the Uskuk blocks into rugged mountain areas, almost completely stripped of their former cover.

This has happened since the mid-Tertiary period, for the lava flows lie within the series of sediments whose age is definitely indicated.

Evidence of planation.—The tracing of a possible ancient peneplane, as represented by the elevated remnants and upland portions of the Uskuk blocks, is of itself little evidence of former cover. It is evidence, however, of a former regional habit. It could scarcely happen that such striking uni-

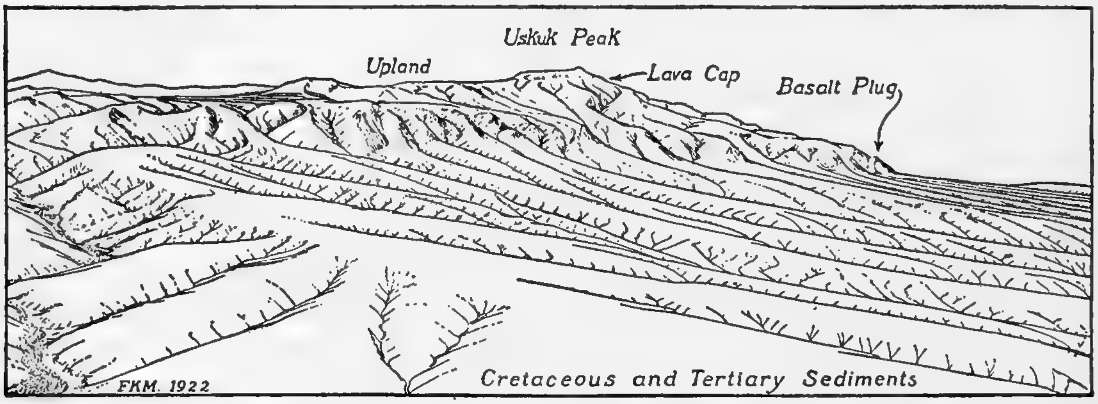


FIGURE 110.—Field sketch of the eastern margin of the Mount Uskuk block. This shows: (1) the lava cap on Mount Uskuk; (2) planation of the crystalline rocks; (3) the abrupt front of the block; (4) the planed and dissected Cretaceous and Tertiary sediments in the foreground.

formity of levels could be developed except by regional planation. This habit, also, is consistent with the rest of the geologic history. General planation surely followed Jurassic folding, and preceded the earliest deposition of Lower Cretaceous sediments. Wherever the floor can be seen without subsequent modification, its simple form is its most striking feature. Not all portions, of course, were covered with sediments at any one time, because there must have been basins and arches in the first deformation stages; but it is probable that all parts were covered at some time, and it is possible, indeed, that many of them were covered and stripped, dissected and recovered, re-stripped and re-dissected, to reach their present topographic complexity.

The ancient peneplane is more pronounced on Baga Bogdo than on Uskuk, but it can be traced on both (Plates XXXII, A, XXXIII, A, and Figs. 106, pages 224–225, and 118, page 269). The broad, gentle, arching sweep of the Baga Bogdo uplift, as one approaches the Altai range, is a most magnificent spectacle. The arch of the skyline from peak to peak, as traced from end to end of the block, at a distance of forty miles, is so uniform that it could scarcely be drawn more truly than the present form of the mountain range itself. It seems impossible for it to be anything but the trace of an ancient peneplane that has been uplifted, arched, and dissected. Yet it was probably at one time covered with sediments, just as were the other areas. A full statement of the Baga Bogdo evidence belongs to another story that must be worked out by additional field investigation.

During subsequent time, while other areas have been lifted and depressed and lifted again, Baga Bogdo has risen highest of all. It is a magnificent landmark, showing a displacement of many thousands of feet, for the peak stands 7,000 feet above the level of the sedimentary plain below. If one adds to this the thickness of sediments which lie on top of the crystalline floor in the Tsagan Nor basin, the two, measured together, must amount to not less than 10,000 feet, much of which must have been attained in the deformations of the region during very late Tertiary time. Baga Bogdo of the Altais appears, therefore, to be a comparatively young mountain, and the stratigraphic and structural evidence of its margins fully supports that inference.

EROSIONAL HISTORY OF THE SOUTH BLOCK OF USKUK

Viewed from every direction, the south Uskuk block is a rugged-looking, much dissected area, rising abruptly from the surrounding country. The margin is sheer on the north side, and is equally abrupt, although not quite so steep and high, on the south side; but the easterly margin is much more broken and more deeply dissected. The difference in marginal feature is due largely to the fact that the structural trend of the formations which make up this block is about N.60°W., thus presenting, both to the north and to the south, the broad sides of the structural units, whereas the ends of the structures come to the margin on the east side. Readjustments of drainage have resulted in extending many of the stream courses east and west, and it is this adjustment to structure that gives the more ragged appearance of the easterly margin.

From the higher central portions of the block, still another feature is presented which is not visible from the plain. We approach these central areas through deep notches cut by streams, and toil up precipitous valley sides that are extremely difficult to traverse. In striking contrast to this steep, rugged topography is the rolling surface of the upland. There is an immediate change to broad, open valleys from the narrow gorges which lead up to them. Evidently the upland topography reaches back to an entirely different history. It must belong to an earlier epoch, and the deep notches leading up to it must represent rejuvenation, caused by uplift or reuplift of the block after erosion had established broader and more mature valleys of an earlier time. This double history is very like that which we read later in the Artsa Bogdo range of the Altai system, where a mature topography characterizes the uplands, whereas all approaches have an extremely rugged, youthful form. (Compare Chapter XV, page 266.)

The valleys leading out to the south and east are long and deeply cut, whereas those leading out to the northern margin are very short indeed, and extremely steep. The block as a whole must have been tilted to the south and southeast, enabling the drainage to establish itself more successfully on that side and to capture nearly all of the watershed of the block, which thus has a very unsymmetrical drainage pattern.

The north block, in which Mount Uskuk itself is located, has a similar topographic habit and history; but it is not quite so striking in its asymmetrical development. The relatively smooth, rolling upland topography is very well developed, and the only approaches to it are through the rugged, gorge-like entrances (Fig. 108). Some of the upland valleys afford good grasslands, where the natives pitch their yurt villages and live with their flocks.

DEFORMATION OF THE MOUNT USKUK REGION

The Uskuk area, including the Tsagan Nor basin, exhibits somewhat definite and detailed evidences of its deformational history. Not only are the deformations of pre-Jurassic time preserved in the Uskuk blocks, in the unnamed block to the east and in Baga Bogdo, but the continued deformations of post-Jurassic time are so related to strata of definitely determined age that their time-distribution and significance in historical geology are unusually well established. In addition to the warpings which must represent the earliest happenings after the post-Jurassic peneplanation, there have been repeated warpings and faultings almost to the present time. The most significant of these are the following:

(a) Faulting and tilting of the Lower Cretaceous strata initiated conditions leading to the erosion break and unconformity above them.

(b) Relative downwarping must have followed to make the region one of subsequent deposition during early Tertiary time.

(c) Warping and uplift raised the Uskuk blocks to an altitude of such prominence that erosion was initiated again, and accomplished the entire stripping of these areas, with the development of their present mountainous topography. This was accompanied by sharp flexures and faulting on virtually all sides, notably on the north and the south, where great faults extend in a general easterly and westerly direction for many miles, and where strata stand on edge or are entirely cut out by the movement (Plates XXXI, B, and XXXIII, A).

(d) The faulting of Baga Bogdo has resulted in lifting a portion of the peneplaned and sediment-covered floor to its present altitude of certainly no less than 10,000 feet, part of which has been accomplished since Pliocene time.

(e) Even the latest Gobi planation surface, which bevels all strata of the region, including the Pliocene beds of Hung Kureh, has been warped (Plate XXX). There is evidence that this warping continues to the present time and accounts for some of the basin-like depressions of the region (Figs. 107 and 111).

Deformation by warping and faulting, therefore, has been in evidence at intervals throughout the time of later deposition, but no folding has been produced. The movements are vertical, resulting in uplift and depression, varying in expression from warping to sharp flexures and marked faulting. Whatever the causes are, they are inherent in the substructure of the earth immediately beneath. They are up-thrustings and down-sinkings of comparatively simple mechanical expression. They may well be the resultant

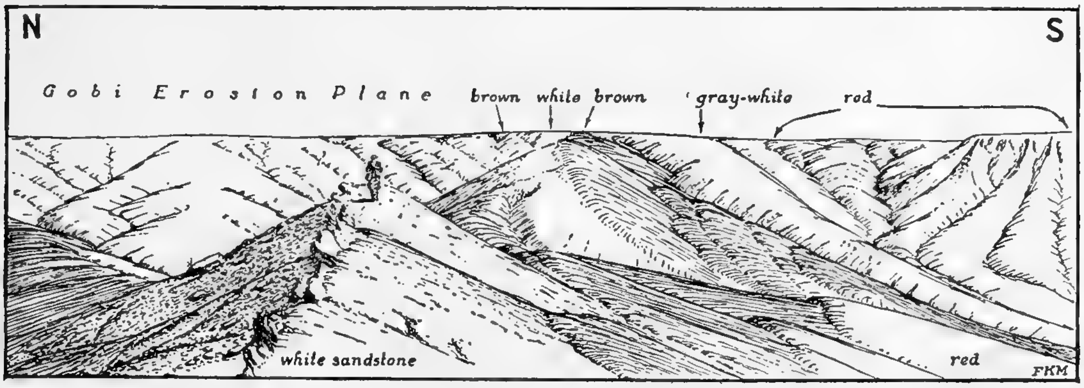


FIGURE 111.—Gobi planation surface beveling tilted strata. Field sketch of planed and dissected Tertiary sediments about thirty miles north of Baga Bogdo. In the badland area formed by the re-dissection of this surface, the upturned beds have developed varying topographic expressions.

of changing isostatic conditions connected with subcrustal volcanism. The most common accompaniment of these disturbances has been volcanic eruption. Outflows of basalt mark certain stages, and basaltic rocks break out through certain lines of weakness. Probably the movements themselves are initiated by some form of volcanism in the interior of the earth, which in some places causes failure of adequate support and in others causes strikingly contrasted uplift. Certainly they are accompanied by surface volcanism. We believe that the movements of the up-thrust blocks of the Gobi are localized, and are quite independent of larger regional influences. They are independent also of the shifting of superficial sedimentary load.

Crowding, with folding and complicated igneous injection and intrusion, accompanied all the deformations up to the close of Jurassic time; but since then all deformations have been simpler, non-regional, essentially local, and strikingly epeirogenic; and the accompaniments have been volcanic activity with the outpouring of extensive surface flows. The whole exhibit suggests that volcanism in one form or another is itself responsible for both types of deformation, and that the nature of the deformation characterizing the different times, varied with some fundamental change in volcanic activity.

THE SALTPAN OF GUCHU BURT

A long and comparatively narrow basin borders Mount Uskuk on the north (Plates XVII, B, page 143, and XXVII). It is bounded on the south by the Uskuk uplifted block with the adjacent upwarped sediments on one side, and on the north by the margin of the crystalline floor, only a few miles distant. It has the appearance of a valley extending indefinitely eastward. It doubtless was once a valley occupied under favorable climatic conditions by a stream.

The general topographic features are favorable to such an interpretation, but it will not account for the chain of minor hollows in the bottom of the lowland. There is no outlet for the depressions, the principal one of which is occupied by a saltpan. From every side the wash is toward the hollows, yet there are practically no modern deposits in them. On the very borders of the saltpan itself one can see exposed strata quite open to present-day weathering, and, although the wash from all sides is toward this ground, there is virtually no cover on it. On the south valley side, toward Uskuk, where the wash comes out from the uplifted fault block, there are extensive alluvial fans sloping down and distributing coarse fragments.

Under these circumstances it is most surprising that the valley bottom is not covered. Even more striking is the fact that the floor is too uneven in depth for any stream to occupy it. There would be many lakes if there were water enough, for the bottom is eroded to uneven depth. Only two origins present themselves: one, that the valley bottom has been warped so that there are basins and ridges along it, and the other, that it has been deepened in places by wind erosion. Possibly both causes have been at work, but apparently the erratic work of wind has been a more prominent process than that of warping. It fully accounts for the exposure of strata in the very bottom, and for the unevenness of depth and form and the very small size of these depressions. The saltpan of Uskuk, therefore, appears to occupy a portion of an ancient valley differentially deepened by wind work, and now lying in a wind-swept hollow which has reached the water-table.

TSAGAN NOR

Tsagan Nor is a lake with an area of several square miles, not too salt to be used for stock, for the Tatsin Gol, an intermittent stream coming in from the west, delivers some water to it. The lake water is only a few feet deep, and the depression it occupies lies in a broad, open lowland, which was produced in part by downwarping, and in part by erosion (Plate XXX and Plate XXXIII, B). The major outlines could have been made most consistently by stream erosion in a former more humid time, but the minor depression occupied by the lake could not have been made either by warping or by water erosion. Apparently the only agent competent to the purpose is the wind, and even this could not have accomplished the work under present conditions. This phase of the local problem will be discussed more fully under the chapter on Climatic Changes (Chapter XXI), where other evidence is assembled. Perhaps it is sufficient at this point to state the problem and to describe the physical features which seem to bear on it.

There are several abandoned strand lines or old beaches above the present water level (Plate XXX and Plate XLII, B, page 396). The only possible way these could have been made is by waves, during the time when lake water stood at these respective levels. The lake, therefore, has stood at various higher levels long enough to accomplish this work; hence, there must have been periods of greater humidity than the present.

The depression occupied by the present lake could not have been made by any known operation of water and wind while water lay in it; but it could have been made by deflation if the water were dried up. It is clearly an erosion product of some kind, and the only process which seems to meet all the demands is erosion by wind. Hence, there must have been a former time still more arid than at present.

The saltpan of Uskuk and Lake Tsagan Nor, therefore, are diagnostic features on which a fluctuating climate has registered some of its recent changes. We see no escape from the conclusion that there have been periods more arid and more humid than the present. There may have been many changes of this kind, but as yet we see no way to work them out in greater detail.

CHAPTER XIV

THE GURBUN SAIKHAN RANGES

THE JOURNEY

On August 19, 1922, the two geologists of the Expedition packed a small camping outfit on camels and with saddle horses started over Artsa Bogdo, with the intention of crossing the next desert basin to the Gurbun Saikhan ranges, which could be seen fifty miles or more away. A local guide undertook to lead the party, which set off with the two geologists, a Chinese cook, and a native Mongol interpreter. Nine days were consumed on this side trip,—nine of the most difficult and trying days of the whole summer, for, in the Gobi region, July and August cover the period of maximum heat. Many very hot days had been passed in July near Tsagan Nor; but at no time in the summer of 1922 was the weather so nearly unbearable as those days in mid-August, when we crossed the desert between Artsa Bogdo and the Gurbun Saikhan.

The first day we crossed the mountains, inspected the south margin of Artsa Bogdo, and established camp. The next day the local guide was sent forward with the camels, while the geologists paused to examine some fossil-bearing sediments. But the guide took the wrong trail, turning eastward along the mountain instead of southward across the desert. The day was almost gone by the time the little caravan was found, and camp had to be pitched again on the southern margin of the Artsa Bogdo range, many miles farther to the east. This mishap was serious, for it upset the original plan of the traverse. It also engendered a well-grounded distrust of our guide and caravaneer. Yet it yielded one bit of good fortune, for the following morning we discovered some chalcedony artifacts of Palæolithic type. The site lies in a little cove-like patch of meadow between two ridges where water is obtainable. On account of the structural relations, we judge that water is furnished even in the most arid times, and the lavas of the vicinity yield a never-ending supply of chalcedony and jasper. These conditions may have encouraged primitive man to dwell there, for it is a spot highly favored with supplies essential to human life. Nowhere else during the summer was a locality discovered so promising for further investigation of primitive cultures.

PLATE XXXIII.

A. FLAMING BADLANDS OF USKUK.

In the badlands along the south margin of the Uskuk block, nearly 3,000 feet of tilted Tertiary strata are exposed.

B. SAND MOUNDS AT TSAGAN NOR.

A sand flat with scattered growth of tamarisks and other shrubs in the Tsagan Nor basin.

PLATE XXXIV.

A. THE INTERMONT SEDIMENTARY BASIN BETWEEN THE ARTSA BOGDO AND THE GURBUN SAIKHAN RANGES.

Artsa Bodgo is faintly outlined in the background about thirty miles away. The view is taken near the only well in the basin, with the geological party in the foreground.

B. TYPICAL MORNING SCENE AT A DESERT WELL.

With an additional guide and better directions, the traverse began more auspiciously on the following morning, so that we finally reached the trail that we should have found the previous day. On this day's journey, however, we experienced some of the most discouraging travel that fell to our lot in the Gobi. Loose, drifting sand, so loose and so difficult to cross that the horses became almost exhausted, prevailed everywhere, and the flaming heat made us long for the little cloud-shadows which brought a moment of relief Only the camels held steadily to their course. Late in the afternoon the party was glad to go into camp beside the only well in the district, about midway between the two mountain groups (Plate XXXIV, A).

A desert well

The ground is remarkably barren and parched. There is a very large tract covered by drifting sand, which is more prominent toward Artsa Bogdo on the west and north than on the south and east nearer Gurbun Saikhan. In spite of its desolate appearance, there is a sparse growth of desert vegetation upon which the Mongols manage somehow to graze surprisingly large flocks and herds. After a day's ride across such ground, it is difficult to believe that water could be reached anywhere. Nevertheless, here in the middle of this desert plain is a well with abundant water. Sheep, horses, and camels come literally in thousands to the well, and here we saw an exhibit of the water situation and its management (Plate XXXIV).

In this plain, as in many others, the water-table lies at no great depth, and water could doubtless be obtained at many other spots. Here it rises to within two feet of the surface, and the supply seems capable of responding to any demand. Apparently this well has served the desert folk from time immemorial. The Mongols' primitive method of handling water requires that it be found abundantly very near the surface. A pole, four or five feet long, with a baby goat skin tied to one end, serves as sweep and bucket. A wooden watering trough completes the apparatus for drawing and distributing water (Plate XXXIV, B). A few flat stones are placed around the mouth of the opening to protect it, and sometimes there is a cover to prevent an animal from falling in. By means of the goat skin, the water is slushed into the trough, and the animals stand there and drink. The water that splashes over helps to enlarge the mud-puddle, which overflows and returns to the well with whatever else may fall there. So there is an endless round from the well to the surface and back again. The only real barnyard mess of the region is immediately around the mouth of the well. It is a discouraging supply for human use, but it is the only supply, and one drinks this water or nothing.

On the whole, the water of the plains is good—surprisingly good considering the surroundings. It is seldom salt or brackish; never bitter, but commonly contaminated; it is cool and wet and therefore comparatively satisfying. It would be easy to improve these conditions, of course, but they are in every respect the conditions that have prevailed here, as in all primitive countries, ever since wells were made.

At such a spot one has ample opportunity to study the people and their equipment. They all come to the desert well. Watching the scene as the herds and flocks straggle in from the skyline of the desert and from yurts that lie far beyond the range of vision, one could almost believe that the world has not moved in 3,000 years. In the early morning, women come, bringing camels laden with casks, to draw their day's supply of water; in the evening the herdsmen drive in their flocks and herds. One sees the usages of past ages repeated. It is the same picture that one might have seen long ago, even in early biblical times, when Abraham and Lot divided between them the pasturage and water privileges,—one taking to the open plain and the other to the hill country beyond. Not a thing has changed from that time to this, except—the rest of the world.

In three days of hard travel it appeared that we were only halfway to our destination, and on inquiry from the natives, who came to the well for water, little encouragement for proceeding farther was offered us. The Mongols would not admit that they knew where the next water could be obtained, and our informants hinted that it was quite uncertain whether we could find any wells. Neither our guide nor the people who came to the well would admit ever having been to the Gurbun Saikhan Mountains, which lay in plain sight. In a country of nomads, such an attitude seemed incredible. We afterward came to believe that this unusually uncommunicative stand was taken because we were then approaching the boundary line between two native states and because another day's journey in that direction would carry us across the border. These men probably had reason to believe that our course would not be favored by the local authorities, and therefore they took this means of discouraging the venture.

Nevertheless, we crossed the basin, and found excellent camping conditions, with good running water, in one of the canyons opening out at the north side of the Gurbun Saikhan range. No sooner had we reached this ground, however, than we were told through our interpreter that the locality was haunted. Mysterious things were said to happen in this canyon. It was said that the grass would poison the animals and that some of them would surely die if kept there overnight. This greatly disturbed our native helpers, but we could not see any good reason for such consequences. An inspection of the surroundings satisfied us that the tradition was unfounded as far as natural conditions were concerned, and, since the party was completely tired out and the animals had to be relieved of further travel, we decided to camp at this place in spite of its bad reputation. That night proved to be the most depressing of our many trying times. Every one was exhausted, the natives were frightened, and both of us were ill. The trip had been undertaken not only at the height of the summer season, but at a time also when vitality had run low from long-continued exertion and illness. We had long ago lost confidence in our original guide, and now found that we could not secure very reliable information along the way. When we turned in that night, the world ahead looked to us as dark as the haunted canyon behind our camp.

Although this seemed quite enough worry for one day, additional trouble was brewing for us, for we had no more than finished breakfast the next morning when four natives appeared and sat down solemnly in front of our tent. Then we were apprised of the fact that these men constituted the local governmental authority and that we were under arrest. Our chief crime seemed to lie in having crossed the state line without proper credentials or permission. There are four great states or kingdoms in Mongolia, and unwittingly we had crossed the line between two of them,—that between Sain Noin and Tushetu.

We told our captors frankly what we were trying to do, and, ignoring the arrest, asked whether it would be practicable for us to go farther up this canyon or whether it would be easier traveling to the crest of the mountains by some other trail. At first they would offer no advice. We were given to understand that traveling was bad in both adjacent canyons, and the local chief advised against attempting to go farther, as it would be extremely difficult to proceed along seldom-used trails. He assured us, in fact, that he could not very well permit us to travel to the point indicated, because the boundaries of his jurisdiction did not extend so far, and that he would be blamed for allowing us to pass through. At first he wanted to take us to the Yamen, or police station of the district, a two or three days' journey away. We told him then that we could not afford the time for such a journey, even if it should gain special permission for us, and that our purpose was only to go one day farther. We were especially anxious to reach the divide in the hope of determining from that vantage point the nature of the country and the larger geological features of the Gurbun Saikhan. In response to his objection that we were likely to be stopped by the local authorities beyond and that he might be accused of negligence, we assured him that we would not advertise the fact of having been interviewed in his territory, and that, in any case, we would take every care not to compromise him. With this assurance he good-naturedly gave his consent for us to proceed up the canyon toward the divide, and seemed quite satisfied with the explanations we gave of our purpose, with our evident desire to avoid complications, and with our promise to return.

The canyon, with its tributary valleys toward the crest of the first range of the Gurbun Saikhan, is one of the finest seen in our Mongolian experiences.

Flowing water, cold and clear and pure, comes to the surface at many places, then disappears for long stretches in the gravels and sands of the canyon floor, only to reappear beyond. These outwellings of water became less frequent as we advanced, and when camp was pitched on the divide that night, there was no water to be had. For the whole day the trail had lain through grassy patches, instead of over the barren ground that had made the trip so desolate between the two mountain ranges; and, as the higher ground was reached, the country became more and more open, grades became gentler, and all the slopes were grass-covered.

From the divide a landscape opened to our view, so attractive that we could well understand the reason for the name, Gurbun Saikhan, which means "the three fair ones" or "the three good places." It refers to the three major ranges rising out of the plain here, which together form rather a complex-looking group of mountains. They are of such height and extent that moisture is precipitated much more abundantly there than in the plain, and as a consequence they are covered with richer vegetation. Seen from a distance, they gleam with a velvet softness in the sunlight, and on the hillsides are numerous flocks. The region looks prosperous, and its people seem to live under especially favorable circumstances compared with the people of the plains. It would be difficult to imagine a greater contrast than that between our camp at the well in the desert, two nights before, and this one on top of the first range of the Gurbun Saikhan.

The return journey

A storm arose during the night, and on the following morning it was still raining. The breaking of camp was delayed for some time in the hope that the weather might change. The whole setting, including the weather, presented a vivid contrast to the experiences of the last two weeks. The beauty of the scenery, the splendid grazing, and the cool air, all led us to think of the place as a park rather than a desert, and as it came in the midst of most disheartening desert experiences, we called the camp Paradise Park. Few places in any grazing country could present a more attractive appearance, and as we looked off across the depression beyond our camp to the flocks on the distant hillsides, we could have believed ourselves in a much more progressive and prosperous country. The whole mountain area is in truth an oasis, a resting-place, surrounded on every side by desert waste.

The gorge and valley, through which we had come to this spot, are known to the natives as Ulan Huataka Ama. Ulan means red, and refers, doubtless, to the red Han Hai beds at the mouth of the canyon. Huataka means water or well, and refers to the many sources of water along the course of the valley. Ama means valley. Therefore, this is "the watery valley of the red rocks."

On our journey back to camp at Artsa Bogdo by way of the well in the midst of the desert, a new road was attempted, and the second day spent in reaching Artsa Bogdo on this traverse was one of the most trying of all our experiences. There were miles upon miles of trail covered with drifting sand, making progress extremely difficult and slow; and then, after reaching the outer edge of the southern slope of Artsa Bogdo, there were additional miles of traverse over alluvial fan and pebble-covered lava slopes, across which the trail could not be followed, and where it was quite impossible, even with local guides, to determine whether we were taking the best course. We simply stumbled along toward a distant landmark in the hope that the close of the day would put us in better surroundings. The ground between the well and Artsa Bogdo is the most desolate part of the region; but as soon as the higher slopes of Artsa Bogdo are reached, grazing is better again and once more one sees flocks in the small valleys and an occasional spring of water.

It took four days to make the return journey. The trip proved to be so heavy a tax on the endurance of men who were sick when they started out, that when camp was reached, the whole party had to go to bed for general recuperation.

GEOLOGICAL OBSERVATIONS AT ARTSA BOGDO

Because of the mistake made by the guide, opportunity was given for a more extended inspection of the southern margin of the Artsa Bogdo uplift than was originally planned. On that side the range descends gradually, while on the north side there is an abrupt escarpment, with much dissection,

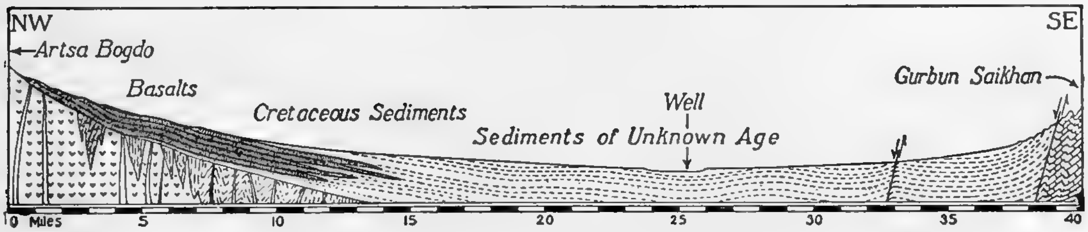


FIGURE 112.—Generalized geologic section from Artsa Bogdo across the intermont sedimentary basin to the Gurbun Saikhan.

to be sure, but still plainly a fault-scarp. The core of the range is made up of complicated geological formations; to the south overlapping lavas and tuffs cover these rocks as they descend beneath the plain. The lavas reach far up into the mountains, where the formations are all igneous. Farther out toward the plain, reddish sandstone sediments lie on top, and in some of them a few fragments of reptile bone were recovered. An extensive area of vesicular and amygdaloidal basalts borders the south side of the range (Fig. 112). On its inner edge this ground merges into the more rugged topography of the mountains, while on its outer margin it slopes gently out into the sediments of the southerly basin. The intermediate ground is a rock desert, covered with broken lava and countless fragments of agate, chalcedony, and jasper. The many-colored pebbles make a brilliant display as they sparkle in the burning sun. They are the so-called "Gobi stones" of the desert, some of which are polished by the Chinese for use as jewels.

This is the character of the country for many miles; but still farther to the east, near the end of the range, the ancient rocks beneath the lavas are exposed again and exhibit a feature not elsewhere seen on such a scale. In the distance the ground looked gleaming white,—far whiter than the ordinary sands. We found that the country rock is an ancient mica schist, not very different from that seen in many other places, representing the complicated pre-Cambrian series; but here quartz veinlets and bunches of vein quartz are so abundant that the ground is literally covered with residuary fragments of snow-white quartz. This seems to be a very local development, but it is of the same origin as the veins and pegmatite dikes seen elsewhere. All were doubtless derived from a granitic invasion from beneath. Special interest was aroused by this extraordinary display of vein material, and care was taken to look for metallic mineralization; but, as far as observed, the veins are barren. There is so little metallic content that weathering does not even stain the quartz. It would be difficult to find, in any region, so barren an exhibit of vein material developed on an equally large scale.

The south basin

The basin country between Artsa Bogdo and the Gurbun Saikhan is a sort of connecting lowland between a great open plain extending indefinitely eastward toward and beyond Djadokhta, and another series of basins lying to the southwest (Fig. 98, page 194). This connecting basin is underlaid by sediments. Most of them are fairly substantial sandstones which are not well exposed. They are covered almost everywhere by a mantle of some kind, commonly drifting sand. In some places, especially adjacent to the mountain ranges, the cover is stream wash. The ground surface, however, is not one of simple accumulation, for the deposits of an earlier epoch, which make up the strata, have been slightly deformed and lifted from their original position, and erosion has carried away the uppermost members. The larger features, therefore, are erosional; only the most superficial and minor forms are depositional. The deposits of recent time have tended to fill up some of the inequalities of earlier erosion, but even this has not destroyed the broad, gently rolling topography.

Only fragments of fossil bones were found, and these are not decisive as to exact age, but Mr. Granger considered them to be Lower Cretaceous. The petrographic and structural habit also gives some suggestion of correlation. When our traverse was made, nothing was known of the nature of the sediments lying farther to the north, in the Oshih basin. Later, they were examined, and are now known to be of Cretaceous age. Their similarity to the beds seen on the Gurbun Saikhan traverse leads us to believe that these also are Cretaceous rather than later. As far as we could see in the distance, no striking changes in the topography of the basin were noticeable; this type of country prevails over a large area. Perhaps, farther to the west, as well as farther to the east, still younger sediments have been deposited on the Cretaceous strata; but in the narrow lowland between the two mountain ranges, only the older representatives of basin-sediment type were discovered.

APPROACH TO THE GURBUN SAIKHAN

The last miles of this journey took us over alluvial fan deposits built in a gentle slope leading up to the mountains. In crossing the fans, special interest was aroused by the variety of pebbles distributed there. They are prevailingly ancient crystalline types, together with igneous rocks. One pebble, however, is of red limestone crowded with fossils, and is quite unlike anything we had hitherto seen in Mongolia. It is certainly of Palæozoic age and similar in structural quality and general aspect to the Devonian of America. Professor A. W. Grabau has since examined this pebble, and says that the fossil fragments, which include crinoids and corals, together with smaller fragments of gastropods and brachiopods, suggest either late Devonian or Dinantian age. We take this pebble as evidence of the presence of mid-Palæozoic strata somewhere in the Gurbun Saikhan uplift. Subsequent inspection of the mountains themselves failed to discover any of this rock in place; but since the stream course which furnished the lone specimen traversed a different part of the mountain block from that reached by us, it is entirely possible that Palæozoic strata are still exposed in some parts of the range.

This piece of red limestone first attracted attention because of its peculiar appearance, and was picked up while crossing a dry distributary course. Although half an hour was spent in an attempt to find additional material, no other fragment appeared. One of the striking things about the whole summer's work thus far had been the failure to discover definitely identifiable Palæozoic strata. The graywacke-slate series on the Siberian border has been considered by certain of the Russian geologists to be of Palæozoic age, but it seems to us improbable that the graywacke-slate series we have seen can bear this interpretation. We were aware that Palæozoic strata had been reported from the Altai Mountains, much farther to the west, but neither in the Baga

Bogdo region nor in the Artsa Bogdo had any such rocks been found by us. Here, however, in the Gurbun Saikhan, more than one hundred and fifty miles east of Baga Bogdo, in the easternmost of the separate uplifts that continue the Altai system, the first scrap of evidence was found pointing to the presence of definite Palæozoic strata. We were later to see considerable bodies of strata of Palæozoic age, still farther to the east in the vicinity of Sair Usu, and it is probable also that there are Palæozoic strata involved in the complex floor of the basin region, in a belt that extends much farther toward the east.

These remnants of Palæozoic strata, however, belong strictly to the ancient floor, and their folded condition has nothing whatever to do with the uplifts that make the present-day Altai Mountains. Each of the three mountain areas, Baga Bogdo, Artsa Bogdo, and the Gurbun Saikhan, is strictly a fault block in its present relations, and the fact that each contains folded strata is incidental and no more significant than the additional fact that it carries still more ancient strata and igneous intrusions of many kinds. In this connection, it is suggestive that the piece of Palæozoic rock is not metamorphosed in the least, nor is it deformed internally, whereas the Khangai rocks—including the graywacke series—are, in the same vicinity, considerably modified in this way. It seems to us that the evidence is fairly conclusive that rocks of two very different ages are here represented: on the one hand, ancient strata older than the chief igneous injections and metamorphism; on the other hand, representatives of Palæozoic age, not nearly so much affected by metamorphic changes and not more deformed than is consistent with simple folding. Although so sweeping a conclusion is surely not allowable on the evidence of a single loose fragment, it nevertheless holds good after the gathering of considerable additional evidence from the Palæozoic strata of the Sair Usu region. The lack of all fossil content in the graywacke series, together with the more complex condition of the rocks, throws a strong balance in favor of the greater age of the graywacke series as compared with the known Palæozoics, which are richly fossiliferous and are in comparatively unaltered condition.

THE FORMATIONS OF THE GURBUN SAIKHAN

The north margin of the Gurbun Saikhan is formed by a fault (Fig. 113). The block is uplifted, and the sedimentary formations that border it on the north are dragged up until they stand virtually on end for several hundred feet. The material is largely a reddish conglomerate, containing pebbles, and interlayered with pebbly sandstone. Some of these beds are well cemented and carry much angular material. The dips are steepest at the very edge of the crystalline rock next to the fault, and flatten gradually in passing northward away from the mountain, until, at a distance of a quarter of a mile from the margin, the dips are gentle and even slightly reversed, inclining southward. Beyond that, they change abruptly again and dip to the north. The strike of the series is about N. 60° W.

They are probably the same beds which were seen by Koslov (1907) in his traverse across the Gobi, and which he considered part of the Han Hai

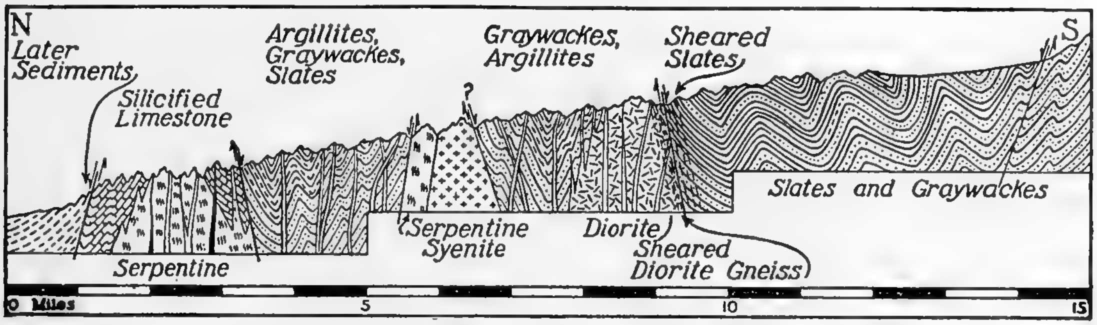


FIGURE 113.—Generalized geologic section of the Gurbun Saikhan.

beds. The thickness observable here must be at least five hundred feet, but no attempt was made to measure the beds accurately. Their age could not be determined, but their petrographic and structural similarity to the Cretaceous strata found in the Djadokhta district farther north, suggests the same general age. A persistent attempt was made to find fossils in the upturned beds, but not a single one was discovered. The general appearance and condition of the rocks are very similar to the rocks seen on the Hsanda Gol and in the Oshih basin. In the absence of definite proof of their age, however, there is no way of classifying them more specifically than to put them with the strata laid down on the oldrock floor of the region, the earliest of which are now known to be of Cretaceous age.

Ancient rocks

A traverse was made from the north margin of the Baron Saikhan to the top of the first divide, a day's journey. The rock formations which we examined are listed in their geographical order from north to south (Fig. 113):

Limestones

A meta-limestone (Specimens 496, 497, A.M. 10,185, 10,186), is the principal formation of the north margin. Its appearance is deceptive, because of extensive silication and considerable injection by igneous material. On this account its primary character is obscure, and it is easily overlooked.

Serpentine

Next beyond the limestone there is a considerable body of serpentine (Specimen 495). There are many irregular, projecting masses of it, cutting up into the overlying limestone. These are encountered, here and there, over a distance of two or three miles along the canyon. The original rock was doubtless a pyroxenite, but other basic types occur with it and are also somewhat serpentinized. The behavior suggests the presence of an igneous mass beneath, from which solutions have been given off that have penetrated the overlying formations. These solutions have furnished the material for transforming and metamorphosing the adjacent rock.

Graywacke-slate series

Farther up the canyon, the great graywacke-slate series was encountered, and this continues as the chief formation throughout most of the distance to the summit. The formation is folded so that the strata stand always in deformed position, and it is much more modified in this block of ground than in most of the other places along the Expedition's traverse. There is, however, no reason whatever to regard it as a different series. The graywacke is the chief formation seen in the northerly Gurbun Saikhan range. It is cut by many intrusive masses, among which are granites and also more basic types.

The same general types continue almost to the top of the divide, where the rocks are concealed beneath the soils of a beautiful open country which forms the crest of the Baron Saikhan block. Not only is the country rolling rather than sharply dissected, but, because of the elevation, it is well grassed, and flocks are to be seen everywhere. This change, of course, is gradual; we had noticed in the journey up the canyon that cattle and sheep and horses were more numerous as the high ground was approached. Here and there a yurt village nestles in a nook in the valley side, and we seized the opportunity to replenish our supplies by purchasing a sheep from one of the herdsmen.

Topographic character of the Gurbun Saikhan

The open character of the upland country is most striking. Its comparatively mature topography belongs to a previous cycle, which has not yet been destroyed by rejuvenation. Farther out toward the margin, a new dissection has developed a youthful character, leaving only here and there much smaller remnants of the former topography. In the more distant upland portion of the range, however, the encroachment of the new dissection is almost entirely wanting, and the open, broad valleys, with rounded hills between, are the dominant features. The smooth surface is disturbed by deformation which includes both block-faulting and warping, not very different from the deformations noted at very many places in the sedimentary basins. In all probability, the sea of mountain peaks which comes into view southward and eastward from the first divide, and which falls into a comparatively even skyline in almost every direction, marks the trace of one of the ancient peneplanes, perhaps the Khanghai peneplane, a prominent feature of the Arctic divide, or the Mongolian peneplane (see Chapter XIX). The peneplane has been dissected, and the upland valleys and high rolling upland country were developed in a second attempt to reduce the region by planation. This was far from complete but must represent at least very long-continued erosion.

Lower than the upland peneplane, there are shoulders within the present valleys, many of which are even now capped with recent conglomerate, well enough cemented to stand as remnants in spite of the renewed dissection. These together seem to represent a still later level to which erosion had reduced some portions of the ground. Perhaps this last corresponds to the Gobi planation stage which is prominently represented on the soft sediments of the plains.

CHAPTER XV

ARTSA BOGDO AND OSHIH

THE ARTSA BOGDO MOUNTAIN BLOCK

ARTSA BOGDO is a mountain unit quite separate from any other. It is not as high as Baga Bogdo farther to the west, but toward the east no others rise so high for hundreds of miles. Like the Baga Bogdo, its longer axis lies east and west, and this makes it appear to be almost in line with the Baga Bogdo mass as though they formed a single continuous chain. As a matter of fact, however, Artsa Bogdo is separated from Baga Bogdo by low ground and is somewhat offset besides, standing a little farther to the south (Fig. 98, page 194). The Gurbun Saikhan, another mountain group farther to the east, is still more completely separated and stands with more distinct offset to the south. This is the characteristic structural habit and arrangement of all the easterly representatives of the Altai system. Still farther eastward the mountainous character is not so conspicuous and finally dies out, although some of the structural characteristics remain.

The representatives of the Altai system in the mid-Gobi owe their uplift and relief to block-faulting. A row of narrow blocks, whose longer axes lie east and west, has been elevated and tilted. The whole system dies out toward the east, each block being lower than its western neighbor. It is an incidental matter that the rocks involved have exceedingly complicated structural features and exhibit close folding nearly parallel to the elongation of the block.

The Artsa Bogdo differs from the Baga Bogdo unit in that the dominant rock formations are crystalline metamorphic representatives of the ancient series, whereas Baga Bogdo exposes an immense area of granite, flanked by metamorphic series. This difference, we judge, is in large part the result of a different amount of elevation and erosion. Most of the stratified and metamorphic cover of Baga Bogdo has been stripped from the underlying bathylithic granite, whereas from Artsa Bogdo the stripping is not so complete and the usual cover of ancient metamorphosed strata is preserved throughout most of the range (Fig. 64, page 150).

The marginal shelf

All along the north margin of Artsa Bogdo a pronounced erosion shelf or pediment exists (Fig. 114). Here rocks of all kinds are beveled and reduced to a comparatively smooth surface. In some places the complicated ancient igneous rocks are involved; at others, later strata, which have been turned up on edge in the uplifting of the mountain. It must be, therefore, that this represents a definite attempt at base-leveling. It is, at least, the trace of some form of planation. Above this general platform rise the mountains of Artsa Bogdo.

Out in the plains to the north there is a similar relation. Small isolated hills stand from 100 to 300 feet above the general level. They are made up of complicated folded strata, largely limestones and schists, all rising from a

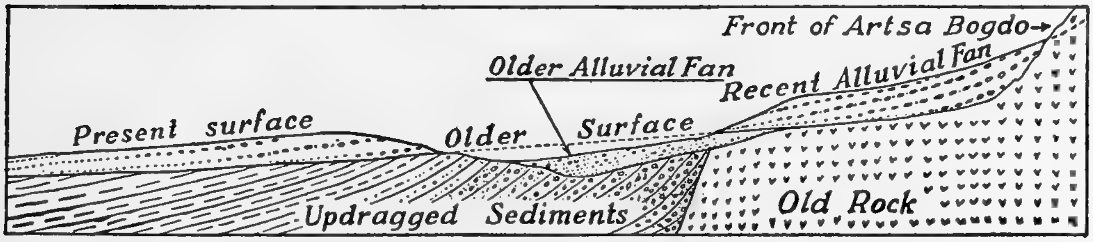


FIGURE 114.—Generalized structure section of the piedmont shelf at Artsa Bogdo.

crude platform level, in the manner of monadnocks. This type of relief, which characterizes the ground traversed by the Kobdo-Kweihwating trail, appears to correspond closely to that of the shelf along the margin of Artsa Bogdo. The origin and correlation of these different planation products is reserved as an unsolved problem for the next field season of the Expedition. There are several alternatives. The planation surface may possibly be a part of the old pre-Cretaceous floor, stripped of its former cover of sediments. Or it may be the pre-Cretaceous floor, stripped and partially replaned by post-Cretaceous erosion which beveled the disturbed Cretaceous strata before Tertiary beds were laid down. Or, it may be in part a still more modern erosion surface. At least, it is certain that since the later sediments were laid down and deformed, new erosion has succeeded in developing platforms and terraces, above which are many remnants, and below which there is considerable dissection.

History of the shelf.—Attention has been called to the deformed condition of the later sedimentary beds, which have been steeply tilted and then beveled by erosion along the shelf following the north margin of the Artsa Bogdo. There are represented three epochs of deposition and three stages of erosion, with structural relations which deserve further description.

A series of conglomerates and sandstones, with interbedded basalts, is turned up on edge, the deformation being due to the uplift of the Artsa Bogdo block. In some portions of the series, basalts are more abundant, but they, too, are tilted at steep angles. Subsequent to their deformation they were planed by erosion; on the new surface lies a much more recent conglomerate, remnants of which are still preserved. The conglomerate fills the inequalities of the old surface and is preserved now chiefly because, in a more recent erosion epoch, those portions which occupied the hollows were well protected. Finally, recent alluvial fan deposits lie on this second erosion surface, and these are slightly dissected. In some places the original slope is so steep that erosion still continues; whereas in other places there is considerable alluvial deposit. This is largely due to warping, but in occasional instances perhaps to changes in supply of detritus.

The alluvial fans and the protected remnants of older conglomerates are the most recent deposits seen along the Artsa Bogdo. One group is still accumulating at the present time, while the other represents an earlier stage in the development of alluvial fan deposits. Beneath the whole series lies the floor of older crystallines, representatives of which may be seen along the inner margin of this pediment or shelf.

Rock formations of the mountain

There was no opportunity for a study of the whole Artsa Bogdo area, but the range was crossed several times and examinations were made at widely separated points (Fig. 64, page 150). The most characteristic rock formations of the area are as follows:

Ancient meta-crystallines and intrusives.—There is a great series of very ancient rocks with considerable petrographic variety, the chief members being: banded blue limestone, finely crumpled schist, bluish ribbon-limestone. black quartzite, buff dolomite, granite, injection gneiss.

Folded sediments and associated eruptives.—A group of infolded sediments occupies some of the higher points of the mountain block. They are conglomerates and sandstones, resembling the type regarded by us as Jurassic, but possibly older. With them are associated porphyry intrusives. How closely these intrusives are related to the sediments we do not know, but they have the same fractured habit and obscure structural relations which have characterized the series of porphyries commonly found associated with the Jurassic strata.

Later igneous rocks.—The two groups of rock formations noted above constitute the chief foundation of Artsa Bogdo; but in the south side of the block, both at the east and at the west end, immense tracts of basaltic flows and bedded tuffs lie unconformably on the others and are distinctly younger than any thus far described (Fig. 115).

The make-up of the mountainous area known as Artsa Bogdo is, therefore, a triple complex, the lowest members of which belong to pre-Cambrian; the youngest represent Cretaceous and Tertiary time, and an intermediate group is tentatively considered to be of Mesozoic age, probably Jurassic. All

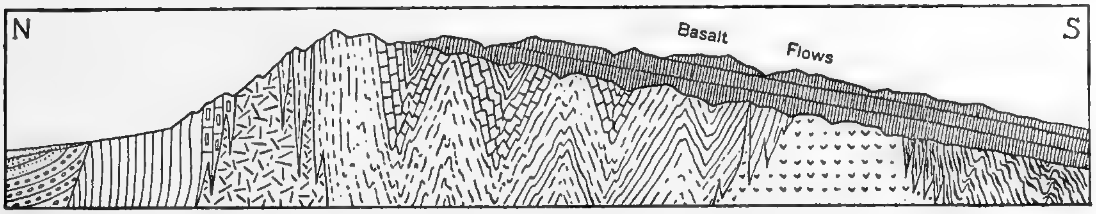


FIGURE 115.—Generalized structure section of the eastern end of Artsa Bogdo.

the sedimentaries, except those of the youngest series, are folded and otherwise much deformed. The crest of the range is made up, in part, of a synclinal remnant of Jurassic conglomerates and sandstones, the structure of which is indicated in the diagrammatic sketch reproduced in figure 64, page 150. On each side of this syncline, and beneath it, lie the still older metamorphic rocks of much more complicated internal structure.

Crystalline limestones are especially abundant in the ancient series. The blue limestones are strongly bedded and banded and, at first glance, give the impression that they cannot be as ancient as are some of the other portions of the older series. They do not carry fossils, but are completely crystalline and vary greatly in habit and quality. Some portions are heavily affected by contact metamorphism. It is hardly believable that so prominent a series of limestones would carry no fossils if it were of Palæozoic age. The fact that the limestones are barren and that they are associated with the schists leads us to conclude that they are pre-Cambrian and belong to one of the oldest series.

Part of the range is occupied by a very great thickness of coarsely crystalline dolomitic limestone which has all the characteristics of a very old formation. These beds may be simply a different member of the same series to which the blue limestones belong, but they have a more ancient aspect. Between them is a crumpled sericitic schist, which undoubtedly has been made from a shale of some kind. Its minor wrinkled structure resembles the corrugated surface of a washboard so strikingly that in the field we called it the "washboard schist" (Plate XXXIX, B, page 303). In addition, there are quartzite beds of considerable thickness, some few of which are iron-bearing and are very black, reminding one strongly of the iron-bearing formations of the Lake Superior district in North America. None of the beds, however, as far as observed, carries iron ore of any consequence—the content is much too poor for any possible use.

The buff dolomite referred to is a very thick formation, and is the most disturbed of all of these old meta-crystalline members. It has been extensively modified by the invasion of granite which forms the core of the range. Because of the structural relations and its petrographic condition, we think that this dolomite belongs at the base of the series represented here.

Granites cut the old meta-crystallines, coming through the uppermost members in bosses, *lit-par-lit* injections and irregular forms. On the southern third of the range, granite is the chief rock and is believed to represent the great Mongolian bathylith. It is cut by many dark-colored dikes which are themselves of variable quality.

Many of these rocks show the effect of contact influences, but the limestones and dolomites are most strongly affected. Some of these are so much

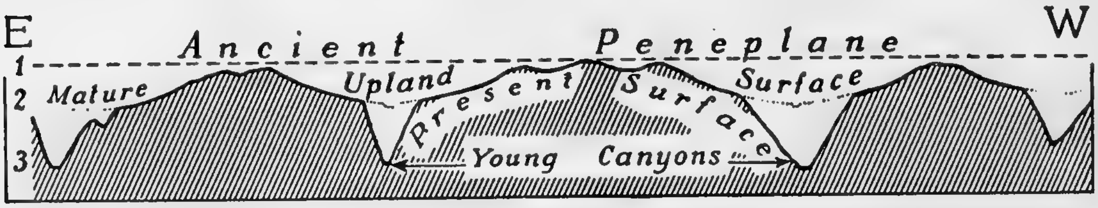


FIGURE 116.—Analytical profile of the upland of Artsa Bogdo. The area records three stages of dissection.

modified by silicification and silication that one cannot tell, from a hand specimen alone, what they originally were. This is especially true of the silicated rocks. Even greater confusion results from weathering, when the rock becomes a yellowish, crystalline mass. The granites can be followed almost down to the level of the plain on the south side, where they are overlapped by basalts and tuffs, and finally, as the next basin southward is entered, by sediments, probably of Cretaceous age.

Toward the east end of the Artsa Bogdo range there is a remarkable development of quartz veins in the schist of the older floor (compare Chapter XIV). They are so abundant that from a distance their milky, glittering disintegration material whitens the landscape, like a sheet of snow. Inspection revealed nothing peculiar in the composition of the ledges, except the abundance of vein quartz. It is unaccompanied by any important mineralization, as far as observed, and this lack allows the rock to disintegrate and weather almost perfectly white, instead of staining yellow or brown in the usual form of gossan.

Tectonic features

The structure of all of the rocks, except the eastern lavas, indicates previous folding. Plainly there have been at least two widely separated periods of folding,—one affecting the ancient rocks that are now metamorphosed, and one affecting strata of supposed Jurassic age, which were deposited on the eroded edges of the ancient series. Although the younger conglomerates and sandstones must have been laid down essentially flat, they also now stand on edge and form a beautiful syncline, a remnant of which constitutes a portion of the highest ground in the range. This is the latest stage of the folding, which in all cases had an east-west axial trend. One is at first inclined to think of the folding as belonging to the uplift which has made the mountains, but this is not the case. Any other block of the ancient floor, lifted above the surrounding region to sufficient height, would present similar features,—that is, ancient crystalline metamorphic rocks with nearly east-west strike and a structural relation indicating ancient folding. It is certain that the rocks of such an uplift as Artsa Bogdo do not owe any of their folding to present mountain uplift, which is of an entirely different origin.

The key to the present mountain structure may be seen along the north margin of the Artsa Bogdo block. Isolated, craggy hills rise abruptly above a very gently sloping shelf, over which one can drive with a motor. At the mountain front, however, there is an abrupt change—so abrupt and steep that one cannot proceed except on foot. That a block has been lifted above the marginal plain by faulting is shown by the structure of the adjacent strata, beneath the shelf at the foot of the escarpment. At a point where a new stream channel has cut a trench into the shelf, later sediments are turned on end for a distance of several hundred feet. The age of these upturned beds is not determined, but they are comparatively unconsolidated and have all the petrographic and structural habit of the Cretaceous and Tertiary beds seen at many other places in the basin regions. It is clear that, since they were formed, a portion of the block which formerly lay below their level, has been thrust up along a great fault, and the broken edges of the overlying strata have been turned up by the drag. Once they must have extended across even the uplifted block. It is necessary to conclude, therefore, that the uplift has taken place in comparatively late geologic time—certainly some time in the Tertiary—and the features of erosion in the upland portion of the mountains indicate that there have been at least two such upward movements, and perhaps others. This estimate is consistent, also, with the extreme ruggedness of the northern margin. Uplift has been by stages separated from each other by more stable conditions, and the latest increment of this movement has been so recent that even the marginal rejuvenation has not caught up with it.

Traces of former sedimentary cover

With such a dynamic history, one would expect to find evidence that ancient folded rocks of the Artsa Bogdo mountains were once covered com-

FIGURE 117A.—The upland meadows of Artsa Bogdo. Sketch from a photograph, showing the open upland valleys.

pletely by younger formations. This is precisely what one sees as he looks along the range toward the east, for there is no mistaking the structural character of the distant parts of the uplift. Instead of a rugged outline, formed by the ancient rocks standing on edge, the topography is decidedly simple, and the structural lines lie nearly horizontal, but bend gently down toward the south (Fig. 115). These lines are formed by a series of lava flows, tuff beds, and sediments that still cover a portion of the uplifted block. We do not know their age, but they lie unconformably on the oldrock floor and descend to the south beneath strata of Cretaceous age. Such lavas are abundantly associated with strata which elsewhere have been proved to be of Cretaceous age. On these bits of evidence we judge them to be Cretaceous also. This seems to have been one of the great centers of volcanism of that time. Few localities in Mongolia furnish so impressive a series of basalts. The whole southerly slope of Artsa Bogdo is smothered by the lava cover. The basalts are stripped and deeply eroded on the higher flanks of the range; they are simply stripped and but slightly dissected on the lower slopes, and along the basin margin they are still covered by the sandstones which once must have had much greater extent.

Topographic features

Within the higher parts of the range there are smooth, open, park-like tracts between the rugged dividing ridges. They look like ancient stream valleys, belonging to a former cycle of erosion, which was so long-continued that mature valleys with broad subdued slopes were developed even in the higher mountains. The modern streams have cut many deep, sharply V-

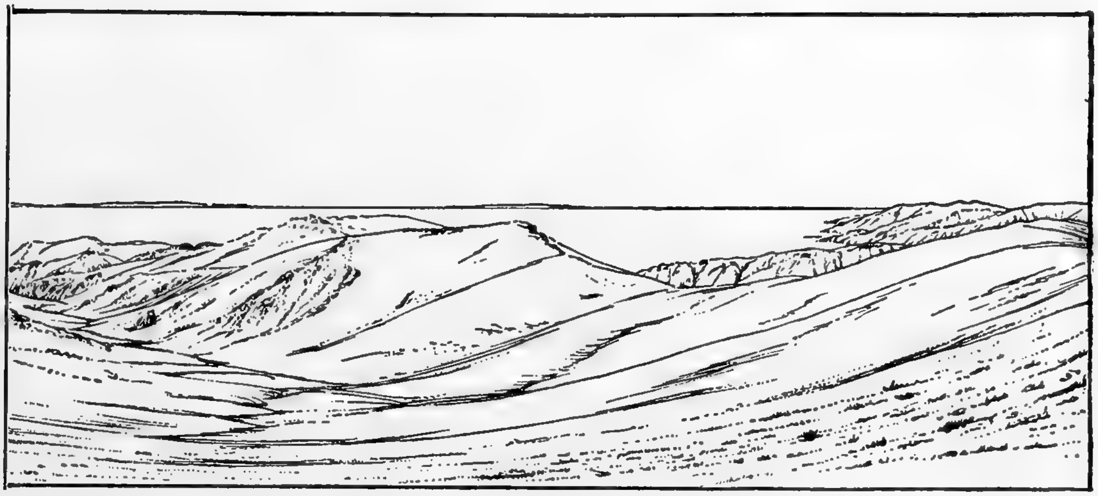


FIGURE 117B.—Continuation of figure 117A. Showing the rugged canyons dissecting the abrupt front, and the broad basin, north of the range, in the background.

shaped trenches across and along the older valleys even to 1,000 feet deep (Fig. 116). The redissection has been on so gigantic a scale that the gentler slopes of the upland parks have been almost completely destroyed over large areas. Thus there are two types of valley in the Artsa Bogdo—youthful, sharply incised trenches, superimposed on broad, mature valley floors, which were themselves the product of erosion of a still more ancient surface, perhaps a portion of the original upland peneplane. The new dissection is probably due to an uplift, after a period of stability long enough to permit open, gently sloped, mature valleys to develop.

Stream pattern.—The stream courses of the newer dissection do not follow either the structure of the rocks or the trend of the older upland valleys; they cut quite independently across all of these features (Fig. 117). Evidently they were laid out on an entirely independent plan. The drainage pattern is superimposed. The major streams probably took their courses on the simple upwarped sediments which formerly covered the block, and, now that the cover has been stripped off of the core in the central portion, these streams still maintain much of their original pattern, with partial adjustment to structure in the tributaries.

Glaciation.—The heads of certain valleys along the northern front of the range are bowl-shaped, and resemble cirques. They are developed on hard rock, apparently quite independent of minor structural control. They are very small for true cirques, but both the form and the distribution of débris led us to believe that the only satisfactory explanation for the feature was the accumulation of ice. Only two or three bowl-shaped valley-heads were noted, and they are not at the highest points of the range. It is our opinion, therefore, that glaciation has been a negligible factor in the Artsa Bogdo. The evidence favors the former presence of a few small ice bodies of the alpine type, but the features are not prominent, and this kind of erosion never became important here.

In discussing the topographic features, it has already been noted that the upland portions of the Artsa Bogdo are characterized by many park-like expanses, with comparatively smooth, grassy floors, separated by more rocky divides. These we attribute to ordinary erosion work carried nearly to old age, at a much earlier stage in the history of the block.

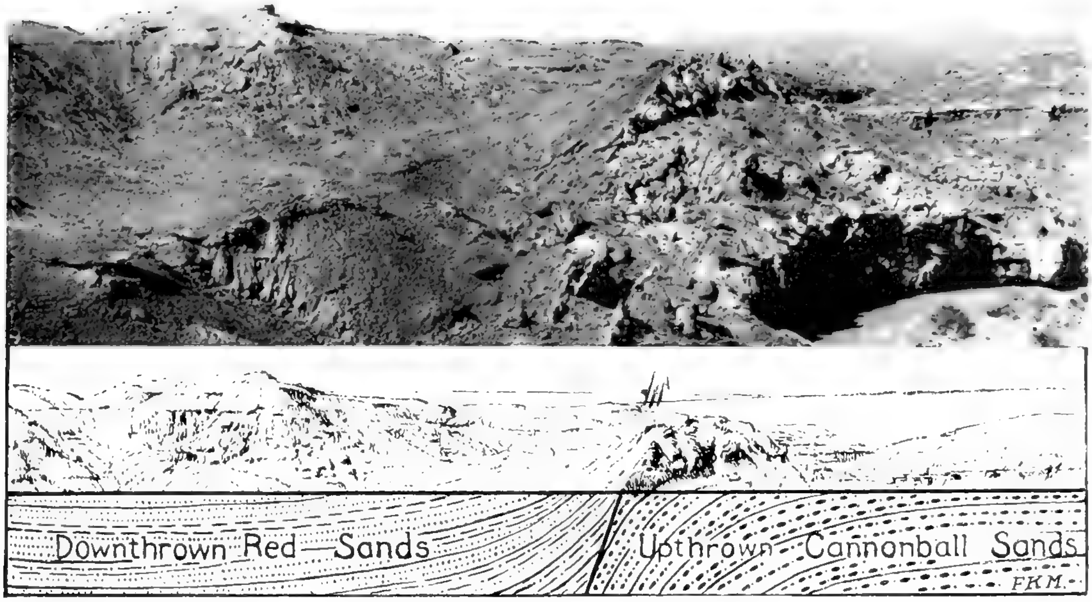
THE OSHIH HOLLOW

While the geological party was engaged in making the side traverse to Gurbun Saikhan, Mr. Granger explored the palæontological possibilities of the depression to the north of Artsa Bogdo, in a district known as Oshih (Ashile), and on our return we spent a day with him in this locality. The following year, additional time was spent there. The traverse from the main camp to Oshih covered about forty miles, the first ten of which led down over the alluvial fans and piedmont slope, stretching out from Artsa Bogdo into the basin to the north; then the traverse continued northward across the basalts and sediments lying on the ancient floor. Most of these are quite unfossiliferous, and in much of the territory the strata are not well exposed and the structure is somewhat obscure.

Features of the locality

The depression known as Oshih is not a structural basin, but is essentially a desert hollow about eight miles wide from north to south, and at least fifteen miles long from east to west (Fig. 118). The erosion features, therefore, are particularly impressive. The high colors of the strata and the badland dissection stand in striking contrast to the simple features of the surrounding rolling plains. A red mesa about three miles long, capped with black lava, stands in the middle of the hollow. It is a striking landmark (Plate XVIII, B, page 146, and Fig. 118). At the eastern end of the mesa, one enters a great amphitheatre-like depression, extending about three miles to the top of the hill Oshih Nuru, which forms the eastern end of the Oshih hollow. The sides of the amphitheatre are fretted into a splendid badland area (Plates XXXV, B, and XXXVI). From the north wall of the hollow, a great bluff about ten miles long, called Urulji Nuru, one can look northward over a perfectly simple, almost level topography representing the Gobi erosion plane; but in the depression everything is minutely dissected down almost to the very bottom. The myriad gullies, joining into fair-sized canyons which open into smooth-

PLATE XXXV.



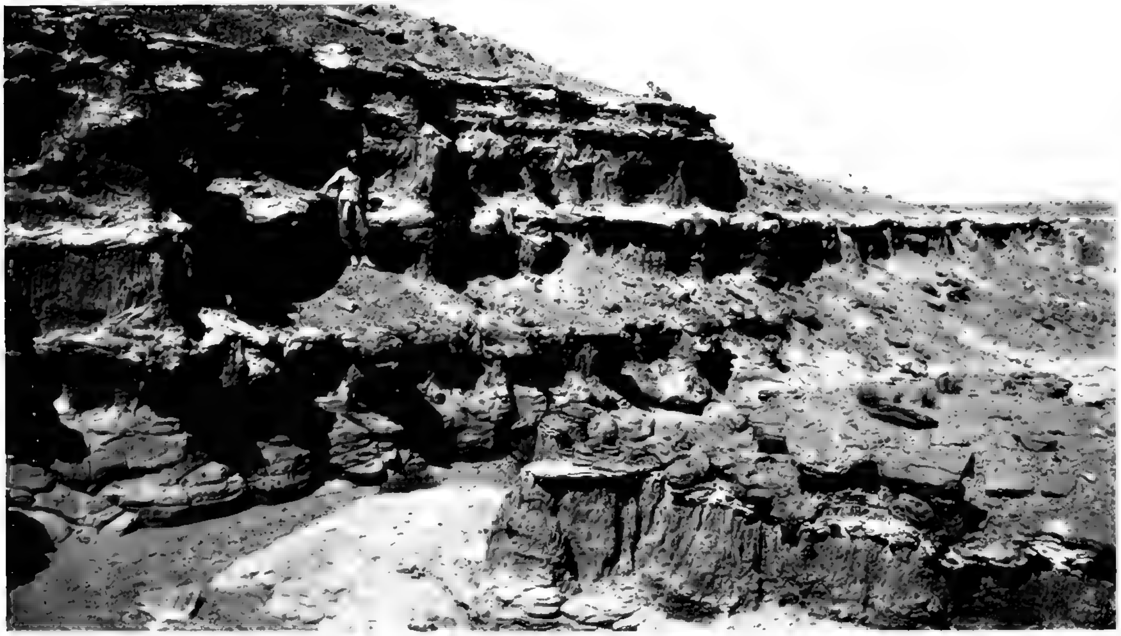
A. A FAULT ZONE IN THE OSHIH BASIN.

B. THE BADLANDS AT OSHIH NURU.

View northeastward toward the badlands and faulted lava flow at Oshih Nuru.

PLATE XXXVI.

A. THE TILTED LOWER CRETACEOUS STRATA AT THE FOOT OF OSHIH NURU.



B. CANNONBALL CANYON.

Lenses of gray, cross-bedded sandstone between red, clayey sands in the Cannonball member of the Oshih formation (*Psittacosaurus* beds).

floored valleys, indicate that the dominant erosive agent in the hollow is running water (Fig. 118). Several inliers of oldrock stand as considerable hills at the western end of the hollow,—two of them, called Baron Khara and Dunde Khara, being made up of folded porphyries, chiefly trachytes of the

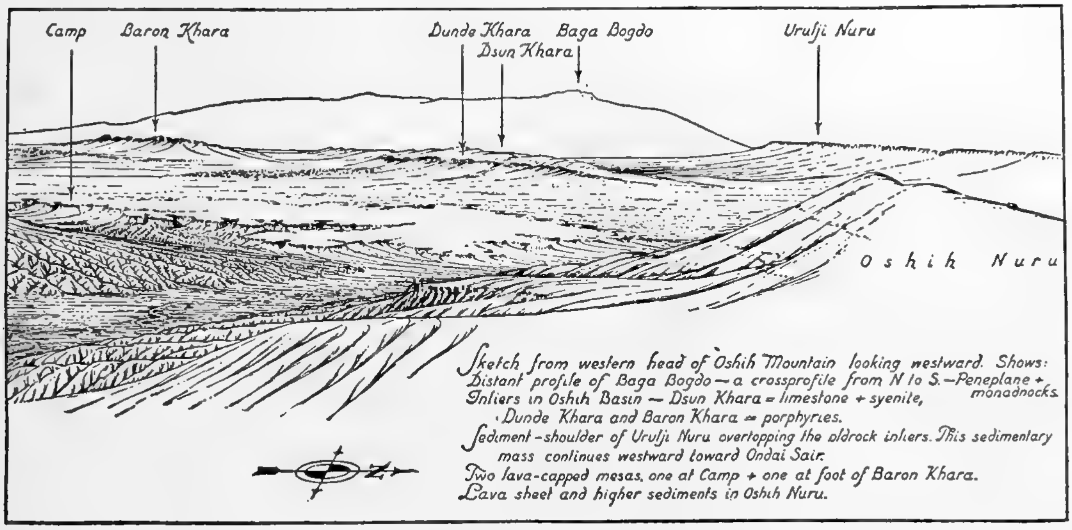


FIGURE 118.—The mesa and stripped inliers of the Oshih basin. Baga Bogdo, seen at a distance of about fifty miles, exhibits a typical cross profile of an eastern Altai range. The high scarp at the right, called Urulji Nuru, represents later sediments that once extended over and entirely covered the hard-rock ridges of the middle distance. Two areas of badlands, one capped by a lava sheet, lie at the foot of these ridges. The same lava covers the broad mesa in the center of the sketch, and it reappears, upfaulted, in Oshih Nuru, in the extreme foreground. The sketch emphasizes three of the dominant processes of the later Mesozoic and Tertiary history: (a) accumulation of sediments, (b) later deformation, (c) local stripping.

type which we have elsewhere seen associated with Jurassic strata. The westernmost inlier, Dzun Khara, is of ancient crystalline limestones, invaded by syenite and granite. There are extensive badlands at the foot of these oldrock inliers, but time was not available to search them adequately for fossils.

The Oshih strata are not folded, but are somewhat tilted, and are cut by numerous faults. The dips are steepest near the faults, where, in many cases, the strata are dragged into a vertical position (Plate XXXV, A). All original fault-scarps have been eroded away, and even the redissection of the region has brought about but little topographic expression of the faulting (Fig. 119). The strike of the faults curves around in a peculiar manner. They are all "normal" faults, dipping toward the downthrow side, which, in most cases, is toward the west. The throw is believed to be moderate; where it could be measured, it ranged from as little as three feet to sixty feet, but in many instances the throw is much greater. Along several faults, recognizable groups of strata have moved into juxtaposition, and by this means we know that the movement must be equal at least to the thickness of the units cut out by the faulting. The full thickness is not exposed for any one of the recognizable members of the Oshih formation in the eastern badlands, but even the

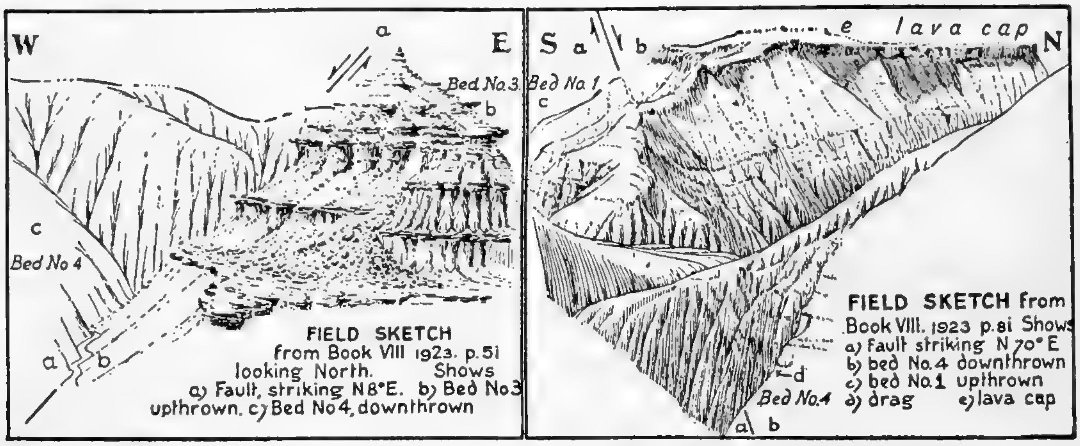


FIGURE 119.—Two fault zones in the Oshih basin. The sketches record the result of deformation in post-Cretaceous time, as expressed in the modern erosion features.

visible parts are enough to indicate that movements of several hundred feet have taken place.

Most of the curving faults strike toward the north, in a direction approximately perpendicular to the Altai front. It is quite impossible to determine the date of the dislocations, beyond the fact that they were certainly later than the deposition and cementation of the sediments, and earlier than the carving of the very level upland surface which bevels the disturbed sediments round about the Oshih hollow. These limits would place the date of faulting some time between Lower Cretaceous and Pleistocene. However, a suggestion is offered by evidence gathered in the region around Uskuk mountain, farther west. The Ondai Sair beds carry a fauna which the palæontologists correlate very nearly, if not exactly, with the Oshih fauna. The Ondai Sair formation was faulted, and the fault-scarps were leveled by erosion before the early Tertiary beds of the Hsanda Gol formation were laid down. There, at least part of the faulting took place before Lower Oligocene time. By implication it may be argued that the faults of the Oshih region are of much the same age.

The geologic column

The following groups of sediments are recognizable:

1. A group of greenish-gray sandstones alternates with red, hard, siliceous clays and red, concretionary sandstones. This is the "cannonball" group, in which spherical sandstone concretions are found. It is surely more than two

hundred feet thick, lies nearer than any other unit to the base of the Oshih formation, and is brought to the surface only in the upthrow blocks along the larger faults. The greenish sandstones, cross-bedded and of variable thickness, are best interpreted as channel fillings (Plates XXXV, A, and XXXVI, B). Reptile bones, including a very perfect skeleton of the small parrot-beaked dinosaur, *Psittacosaurus*, were found in the red sandstones.

2. A group of thin-bedded red sandstones alternates with thick beds of hard, red, sandy clay. The sandstones are less commonly greenish gray, but the clays form the principal ingredient. In one section, one hundred and eighty-five feet could be seen; but as the bottom is not exposed, the thickness is surely greater than this figure. No fossils were found in this group.

3. A group of pink and buff clays. The clays are color-banded, and locally contain thin partings of sandstone. They lie immediately under the lava bed, and form the body of the central mesa. The thickness is unknown, because the base is concealed by the red clay-and-sand group, which is upfaulted at the eastern end of the red mesa (Plate XVIII, B, page 146, and Fig. 119).

4. A gravel group of rather uncertain position. It is found downfaulted against the cannonball group, as is the younger unit, and it seems to bear the same relation to the red clay-and-sand group. It forms a high hill southeast of camp (Fig. 118), where a thickness of at least two hundred feet is visible. The bottom is not exposed, and the upper part has been eroded away. It is probable that gravel members are a matter of locality rather than of horizon, for a thick gravel deposit underlies the lava cap in part of the hill Oshih Nuru (Plate XXXVI, A,), while fine pink clays underlie the same lava at the red mesa.

5. A group of brown clays overlying the lava flow. It is very well exposed in the eastern end of Oshih Nuru, and brown clays that may be its equivalent are seen in the north wall of the hollow at Urulji Nuru. The gigantic sauropod *Asiatosaurus* was found in this layer.

6. A group of gray, thin-bedded deposits, shales, sands, and limestones. The latter are thin sheets of calcium carbonate—some beds composed of vertically directed columnar crystals, others of cone-in-cone structure. The shales include thick deposits of typical carbonaceous paper-shales in which our brief search failed to reveal any fossils except some macerated plant fragments. Selenite crystals were present, suggesting that possibly the shallow lakes, in which these beds were laid down, were bitter waters that did not support the rich fauna which at Ondai Sair is preserved in paper-shales just like these in all respects, except for the absence of gypsum.

7. At Oshih Nuru, only gravels, which may be of recent age, cap the gray beds. But on the north flank of the Shah Ola, in a high hill of conglomerate

some eight miles east of camp (Fig. 98, page 194) the paper-shales are succeeded by fine red sandstones of well-assorted quartz grains. They closely resemble the Djadokhta sand; but twenty miles farther east, near the temple, Sairim Gashato, these sands were found to contain bones which Mr. Granger thinks represent the Oshih fauna. In a concretionary stratum of the Sairim sand, some thick-shelled pelecypods, very like those collected at Iren Dabasu, were found.

The measurable thickness of these units does not indicate the true total thickness of the beds in the Oshih basin. Neither the top nor the bottom of the local series of beds is in sight. The simple elevation difference between the bottom of the basin and the south basin wall is 860 feet, neglecting the dip, which, in this part of the basin, is slightly southward, so that it would have a tendency to increase the total thickness. At least 900 or 1,000 feet might be given as directly measurable in this way. When the north valley side alone is estimated for thickness, it measures, in simple elevation, difference from the north wall to the bottom of the valley, 560 feet. The valley is two miles wide, measured from the red mesa, and the average dip is something approaching 10°. This figure would allow an additional thickness, within the range of two miles, of 740 feet; so that the total thickness of exposed strata on that basis would be about 2,300 feet. It was impossible to check these figures closely; but from them alone it is reasonable to place a thickness of approximately 2,000 feet for all the strata exposed in the Oshih basin. Half of this is directly measurable, and the rest of it is estimated on dip and distance. (Specimens Nos. 534, 535, 536, 537 and 538, A.M. 10223, 10224, 10225, 10226, 10227.)

On the south wall of the hollow, opposite the western end of the red mesa, there are many stacks or pillars of chalcedonic silica, which look, at first glance, like a grove of petrified trees. They are all in one small area near the foot of a lava-capped cliff, and have weathered out of fine clay-like sediments which may prove to be volcanic ash, and which dip gently toward the southeast, passing underneath the basalt cover. The stacks seem to represent a replacement of ash by colloidal silica, along vertical channels which served as conduits for the escape of uprising hot waters, at the time of volcanic activity. It is possible that they may be silica fillings of geyser necks, but they appear to lack the concentric structure one would expect in this case (Plate XXXVII).

The overlying lavas at the south rim of the hollow are several hundred feet thick, and dip south and southeastward toward the Altai front. They contain numberless amygdules of chalcedony, agate, and quartz, which on weathering out, literally cover the ground. They are called "Gobi stones" by travelers.

The Oshih sediments and their associated lavas dip generally southward

PLATE XXXVII.

RESIDUARY STACK OF JASPERY SILICA BELONGING TO THE ASH BEDS OF OSHIH.

toward Artsa Bogdo, just as the Cretaceous and Tertiary sediments at the foot of Baga Bogdo dip southward toward the Altai front. If the Oshih be the same formation as the succession of lavas and red sediments seen by us south of the Artsa Bogdo, it may very well be that the site of the present range formerly was covered by the Oshih formation.

CHAPTER XVI

PROBLEMS AND AREAS DESERVING SPECIAL STUDY

INTRODUCTION

One of the specific objects of the Expedition was to determine the nature of the geologic problems of Mongolia and to locate areas where additional investigations would be likely to produce results. The first season was strictly a reconnaissance venture, and it could best meet the original requirements if its findings proved suggestive and supplied reliable guides to new fields of investigation.

When the Expedition started, there was complete uncertainty regarding the prospect of locating fields of palæontologic importance; but, fortunately, several productive localities were found, and it was possible at the close of the season to indicate with precision the most important of these fields and to suggest the nature of the returns that might reasonably be expected from them. The results of the second season fully corroborated these forecasts.

In similar manner, it is now possible to indicate the nature of other geological problems suggested by the studies which were made in the interpretation of the geologic structure and the geologic history of the region. In some cases, these problems are more difficult to carry forward than are the locality studies in proven fossil fields; but their nature can be stated quite as definitely, and it is possible also to indicate the district in which important data pointing toward their solution can be obtained.

A great number of minor problems, also, have presented themselves in the course of these field studies. Many of them, of course, are only partly solved. It is beyond the purpose of this chapter to state them. They are characteristic of every such investigation, and have to do with the working out of geologic structure and history in greater detail and with greater certainty.

In the course of the reconnaissance season, progress was made on several special locality studies, as opportunity offered, and the results are included in the preceding chapters. In each case, we have been rewarded for the effort put on them, either because of important faunas discovered or because of suggestive structural relations determined. The special districts embrace the study of the Iren Dabasu basin, the hot springs area of Sain Noin, the Uskuk Mountain area. In the second season, 1923, certain problems, suggested by the first reconnaissance, were pursued with excellent results. They include the special stratigraphic and palæontologic studies of the Djadokhta district, the Shara Murun locality, Ardyn Obo, Oshih (Ashile), and a restudy of the Iren Dabasu-Irdin Manha district.

Those suggested for additional consideration fall under the following heads (Fig. 120):

SEDIMENTARY BASINS AND POTENTIAL FOSSIL FIELDS

The area of the great pass

In the Wan Ch'uan Hsien Pass, above Kalgan, the trail crosses later sediments for several miles as it approaches the top of the escarpment on the edge of Mongolia, where strata, at least 5,000 feet in total thickness, are

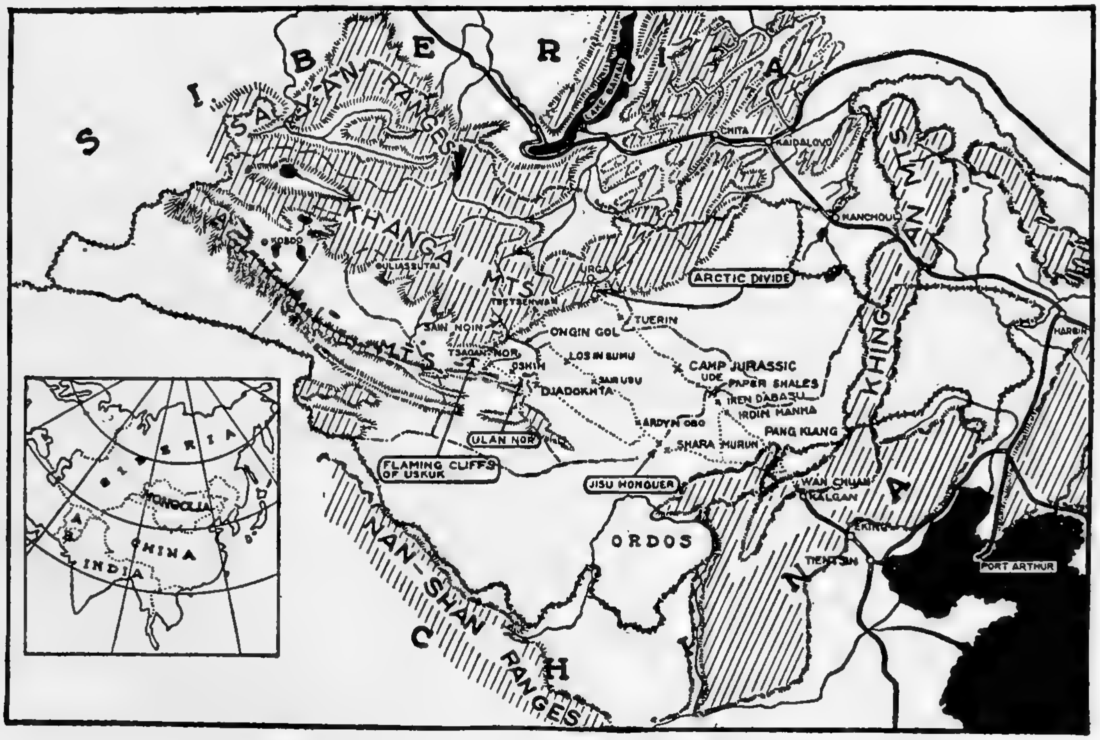


FIGURE 120.—Outline map showing the location of the places deserving additional study.

exposed by rejuvenated erosion (Fig. 5, page 47, and Plate XLI, A, page 389). Most of the beds are unfossiliferous, but a few have been found to carry fragments of fossil bone, and others, obscure plant remains. They are clearly a great series of sediments of the same structural relations as the later sediments of the desert basins proper, and they appear in much greater thickness than is represented in any other locality of our experience—unless it be in the Tsagan Nor basin. It is entirely likely that more than one series of strata is represented. Their exact age is not known, although we infer from the fragmentary material in hand that the greater part of them are of Cretaceous age. The area of the great pass is, therefore, one of the most promising localities for special study. It is not difficult to reach, and it promises important evidence in the chain of geological history.

Following up the conclusions reached at the close of the first season, 1922, Prof. George B. Barbour of Peking was advised to make a further investigation of the area. Several brief notes have appeared, and additional results are promised in due time (Barbour, 1924).

P'ang Kiang

P'ang Kiang lies on the main caravan trail toward Urga and is the first great basin north of the pass where strata of later age are well exposed (Figs. 10, page 53; 99, page 198, and 100, page 199). No very great thicknesses appear, but there are long stretches of erosion-scarps and valley sides, where strata can be examined in detail. The beds are chiefly unfossiliferous, although the one fossil found indicates Tertiary age. It might prove to be a fossil field of some consequence, but in any case it is a field where additional stratigraphic evidence is available, and it lies within easy reach of Kalgan as a center of operations.

The paper-shales of mile 299

A basin of moderate size is crossed by the Urga trail about 290 to 300 miles from Kalgan (Fig. 16, page 62). The area was crossed rapidly, with only two halts in the basin, one of them at mile 295, where reddish sediments of coarse grain and somewhat limy character were seen, but no fossils were found. A few miles farther on, at mile 299, after crossing the Gobi upland, the trail passes down over an erosion-scarp into a depression in which are several outlying remnants of shales. An inspection of two of these showed the presence of a very fissile paper-shale of black carbonaceous appearance and, as far as observed, without fossil content. Only a few minutes were devoted to the inspection, and the failure to discover fossils should not discourage further study of the locality. This was the first encounter with the paper-shale type, and its importance was not appreciated. Later studies, however, several hundred miles farther west, revealed a very important fauna of Lower Cretaceous age in exactly similar paper-shales at Ondai Sair (Chapter XIII). Apparently the area at mile 289 carries the same series, and if the beds were inspected carefully, following up the outcrops both to the east and to the west of the trail, it is almost certain that an important link in the history of the region could be determined. It is one of the few places in the Gobi region where paper-shales have been seen.

The flaming cliffs of Uskuk

On the west side of the Uskuk area, which was made the subject of a special areal study on the reconnaissance, there is a remarkable exposure of variegated and highly colored sedimentary beds, called in the field "the area of the flaming cliffs." They are undoubtedly a continuation of the sedimentary series underlying the Tsagan Nor basin (Fig. 120). We believe that they represent the lower part of the Tertiary column, and probably are to be correlated with the beds exposed in the badlands of the Hsanda Gol, already described (page 233). At the new place the beds are turned up on edge against the south Uskuk block (Fig. 121), so that minute inspection could be made, and these

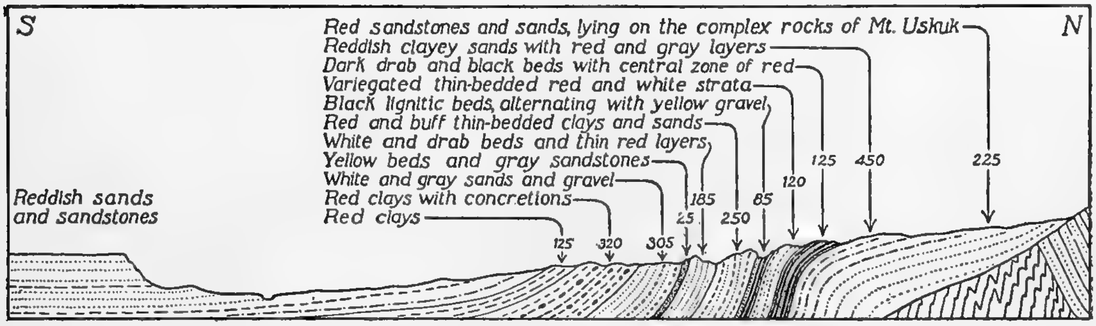


FIGURE 121.—Cross-section of the Flaming Badlands south of Mount Uskuk.

same conditions appear to extend far to the west. How well they are exposed farther along in that direction, we do not know, but the structural conditions indicate their continuation. They are probably exposed at other places along the same fault line that marks the south side of the Uskuk block. The beds actually examined at the flaming cliffs proved to be poor in fossil content, but there is reason to believe that productive spots could be found.

The strata are, of course, closely related to the strata described in the Uskuk mountain area; but it may be that the lower members of the series not so well exposed in the places already studied, could be seen in greater detail on the westward extension. It is apparently as encouraging ground as the Hsanda Gol locality itself, and promises results, both as a fossil field and as a basis for a better understanding of the stratigraphy of the later sediments.

Oshih (Ashile) basin

Out in the plains country, twenty-five miles north of the Artsa Bogdo mountain block, a great series of Lower Cretaceous sediments is exposed in fine erosion remnants and badland country. (See Chapter XV, and Plates XVIII, B, page 146; XXXV, XXXVI, XXXVII, and Figs. 118, 119, pages 269 and 270.) The locality is known as Oshih. Several days of exploratory inspection during the first season revealed dinosaur-bearing strata, and one excellent skeleton was found by Mr. Granger. The large area of splendidly exposed beds offered encouragement for further study.

Only ten days' inspection could be given to the locality in the second season, so that, despite the work of two summers, the vast badlands of Oshih remain a legacy for future investigators. In 1923, other areas of badlands were discovered, east and west of the original camp. A few fossils were found in the new eastern extension of Oshih, some miles north of the temple Sairim Gashato. Several areas of paper-shales like those of Ondai Sair were found, but no fossils were seen in them.

Undoubtedly there are exposures of like nature at other places in the large basin extending eastward from this point; from the mountain-tops it is possible to discern badland areas in the distance. Perhaps the region to the north would also be a promising area for additional inspection, but, in all probability, the strata in that direction are of later age than those at Oshih.

Djadokhta

A locality, known to the natives as Djadokhta, is reached on the Kobdo-Kweihwating trail, almost due north of the great mountain mass of the Gurbun Saikhan (Plates I, XIX, page 156; XX, B, page 157, and Figs. 67, page 159; 152, page 356). The place was discovered and the nature of its fauna determined on the homeward traverse of the reconnaissance expedition in September, 1922. Only two or three hours were actually spent in inspection of the locality, but in that time an unusual number of dinosaur specimens was recovered, together with one dinosaur egg. These finds showed that not only were the remains abundant, but, more important still, they were of a rare and unfamiliar type. The urge to hurry the return journey prevented more detailed examination, but enough was done in a few hours to prove that here is one of the great fossil fields of Mongolia; and on the return of the Expedition to Peking, when the following season's work was tentatively laid out, Djadokhta was listed as one of the principal places for detailed examination. The results of the following season, 1923, fully corroborated the opinion, for the locality yielded an extraordinary harvest of discovery. The fossil remains, even those of delicate structure, are unusually well preserved, showing that peculiarly favorable conditions must have prevailed at the time of deposition and burial. Twenty-six dinosaur eggs were recovered in the course of a month of exploration in 1923, with no less than thirteen nearly complete skeletons and more than seventy skulls. In addition, a few skulls of minute, rare mammals were obtained.

The area, of course, is not exhausted; but sufficient work has been done to show the range of possibilities. In a formation so favorable to the preservation of the frailest material, there is encouragement to further work.

Overlying the Djadokhta sands is a group of clays and gravels called the Gashato formation, which yielded a very small collection of rare and primitive mammals belonging to the Paleocene. The extent of this formation is enormous, and as yet only a few days' time has been spent upon it.

North and northeast of Djadokhta there is an immense basin, well-exposed in places, on which almost no work has been done.

Ardyn Obo

At Ardyn Obo, on the trail between Sair Usu and Kalgan, a great erosion escarpment, which stretches westerly as far as the eye can reach, exposes more than two hundred feet of Tertiary strata (Plate XXI, page 182; Figs. 83 to 86, page 175, and 137, 142, page 324). An inspection of these beds was made during the first season, at the point where the trail touches the escarpment, and several skulls of Rhinocerotidæ were found. Fragments of other forms were found also, but the beds, as a whole, were not very prolific. Apparently the district is one well worth additional exploration in the prospect of finding beds of more varied content. It is favorably located on a main trail, but probably has the disadvantage of a narrow range in age.

Shara Murun

At Shara Murun on the Sair Usu trail, one hundred and five miles southeast of Ardyn Obo, where a halt of only half an hour on the return journey revealed fossil bones and teeth, a locality of special promise was discovered (Plate XXII, B, page 183; and Figs. 89, 90, page 180; 99, page 198; 100, page 199; 143, page 339; and 146, page 340). An exposure of later sediments, carrying fossil remains, extends for several miles. The examination at that time, although insufficient to determine the possible range, was enough to show clearly that the locality deserves much more attention. Further examination was made the second season, and the connections of this basin with the Irdin Manha to the east were reasonably well traced, yet the extent of the basin is so great that it seems wisest to class it among the less explored regions as a hopeful project for further study.

Ulan Nor

Ulan Nor appears to be an area of deposition at the present time. The Expedition on the return journey passed about fifteen miles east of the lake, and crossed several miles of deposits where anastomosing streamlets are now stripping the basalts lying to the east and distributing the sands. It is a difficult country to traverse—dangerous for heavy motor cars—but it is one of the few places in the Gobi region where the Expedition encountered active deposition. On this account it ought to repay critical examination. Here one might make out the nature of the deposits made under present climatic conditions. Somewhere in the region, sediments must still be accumulating, and perhaps this section would throw additional light on Pleistocene and Recent history. It may hold the key to a better understanding of the later sediments of the Gobi region, and it is well worth the critical examination recommended. It does not necessarily promise important fossil returns; but if it produces any returns at all, they are likely to be quite different from those already secured and would aid materially in unraveling the problem of the later geologic history of Mongolia (Fig. 98, page 194).

The badlands of the Ongin Gol

The Ongin Gol has trenched the Gobi upland for a hundred miles, and in places the strata of the plain are exposed (Figs. 69, 70, page 160). On the whole, however, there is little encouragement for examination of the Ongin trench itself. Twenty or more miles to the west of the river, a short distance south of the latitude of the temple Ongin Gol In Sumu, one can see extensive badlands (Fig. 98, page 194). Brilliantly red strata are exposed; and undoubtedly there is a favorable opportunity for inspection of additional sedimentary strata belonging to the great series of basins lying between the foothills of the Khangai Mountains on the north, and the Altai uplifts on the south. It is probably a difficult locality to reach, but it is accessible from the vicinity of Ongin Gol In Sumu with a camel train, even if not by motor.

STRUCTURAL AND HISTORICAL PROBLEMS

In the following list a different type of problem is presented. In certain of the localities mentioned, the chief feature is one of structural relation, while in others the major point is one of age, correlation, and historical meaning.

The Camp Jurassic area

At approximately three hundred and seventy-four miles north of Kalgan, the main Urga trail crosses one of the outcrops of Jurassic strata. For a few hours before darkness set in, we inspected the locality and found that the place exhibits extraordinarily well some of the critical structural relations of the Gobi region. Here later sediments are tilted on edge by a sharp flexure which brings the oldrock, in this case represented by Jurassic strata, within reach of surface erosion (Plate XI, A, page 61, and Figs. 18, 19, page 65). A small, unsymmetrical, structural dome is breached so that three different series of strata are exposed. We judged, from the short inspection given, that Tertiary, Cretaceous, and Jurassic strata are all involved in this structural unit, which is one of the smaller and sharper uplifts of the Gobi basin (Fig. 122). With it are associated basaltic eruptives that may have special significance, and the

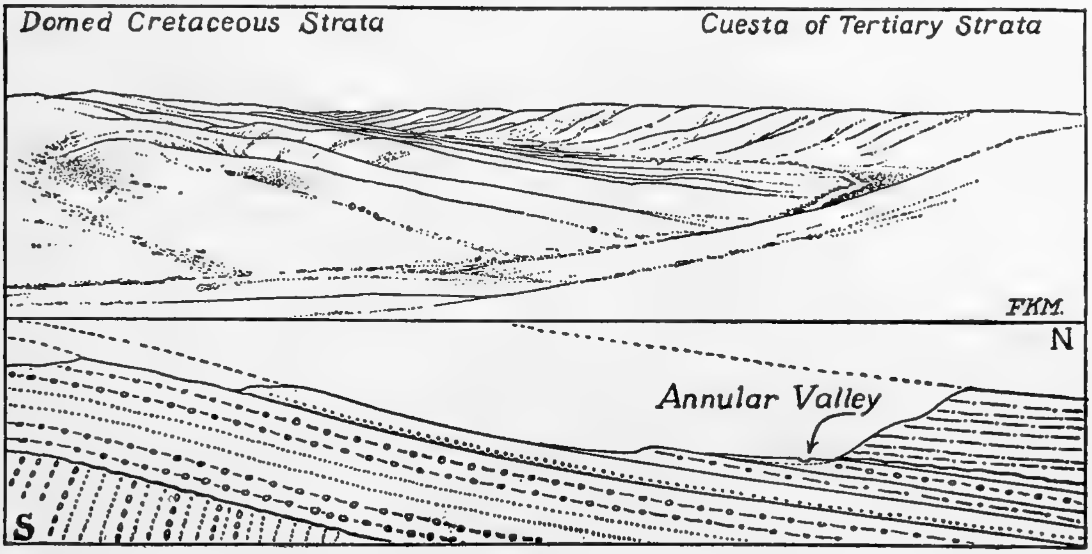


FIGURE 122.—The northern slope of the dissected dome at Camp Jurassic showing cuestas and annular valleys.

typical erosion features of a dome are beautifully developed. The intensive study of an area, five or six miles from north to south and perhaps ten miles from east to west, would make one of the finest contributions to structural geology afforded by the Gobi region. It promises fossil remains in all the formations, although it is not recommended as a fossil field. Even in the short time devoted to it, this place proved to be especially suggestive and helpful in working out the structural and stratigraphic history.

The crystalline upland east of the Ongin Gol

Between Canyon Brook and the Ongin Gol, along the trail toward Sain Noin, there is an upland block of complex structure (Fig. 47, page 117, and Fig. 49, page 121). In it are ancient crystalline metamorphics made from sediments of various types, cut and injected by dikes and stringers derived from the granite bathylith. The rocks belong to an era promising returns along structural, stratigraphic, and historical lines, as well as in physiographic forms. It is a region of depressions in the granite, which are deep enough to hold water and are without adequate explanation under present conditions. The ancient sediments in the block exhibit a succession of conglomerates, limestones, and slates, showing different degrees of metamorphic complexity, and apparently representing several entirely different formational series of ancient types.

The ground was covered too rapidly to enable us to make the required determinations of structural relation and succession. This is especially unfortunate because we rushed through one of the few localities where we might have been able to distinguish the different ancient series. An area of complex gneisses ends abruptly against a zone of conglomerates, which is succeeded by less complex schists, by slates, phyllites, and more conglomerates, and then by graywackes overlaid by Jurassic strata. How important the breaks are between the different series and what significance the conglomerates have, we do not know, but in this locality these questions could be determined.

Transition country of Gangin Daba

Approaching the mountain country south of Urga, the trail crosses a broad succession of gneisses and schists of various kinds, of high structural complexity and apparently of great age. They continue with little change—except that they apparently become somewhat more simple in petrographic character—to the vicinity of the mountains which separate the desert from the Tola River valley (see Chapter IV). Between miles 619 and 623 a change takes place (Fig. 27, page 81). Instead of schists, phyllites, and gneisses, the country rock becomes wholly graywackes, slates, and quartzites, with a few jasper beds. The graywacke-slate series is certainly simpler in petrographic quality, and therefore is regarded as younger, although the relation between it and the formation next to it could not be ascertained. This critical stratigraphic and historical point could be determined here but the Expedition rushed past without stopping. The whole stretch of more than twenty miles deserves detailed structural interpretation, and it would yield definite returns toward the unraveling of the structural features of the pre-Cambrian.

Sair Usu

Nine miles southeast of Sair Usu, Palæozoic strata, chiefly limestones, are found (see Chapter X, and Fig. 78, page 171). They are deformed by folding and faulting but are so little modified in other respects that the fossils are not destroyed. Our meagre collection from the richly fossiliferous beds indicates that the age is Dinantian. The formation, which appears to continue indefinitely westward, would yield unusually good returns toward a better understanding of Palæozoic stratigraphy. This is one of the few places in central Mongolia where fossiliferous Palæozoic strata occur under conditions favorable for detailed inspection, and where their relation to other formations could be determined. It deserves careful and detailed examination.

Los in Sumu

At Los in Sumu, about seventy-four miles west of Sair Usu on the Uliassutai trail, an exceptionally good opportunity is afforded to study the edge of a sedimentary basin where it adjoins the margin of hard rock. On the north are rugged hills of the graywacke-slate series, which descend in spurs to a smooth floor. One may suppose that sediments have been stripped from this floor, for the level-lying gravels, rubbles, and sands form a low scarp about a mile south of the oldrock hills (Fig. 74, page 167). It would be interesting to find an answer to such questions as the following: What is the age of the sediments? Are they beveled by an erosion plane, or is their present surface one of deposition? How was the floor formed on which they are laid down? By what agencies was the inner lowland formed which now separates the infacing scarp of sediments from the hills of ancient rock? What has become of the sediment removed from the site of this inner lowland?

Jisu Honguer

A second area of Palæozoic strata was discovered at Jisu Honguer, after crossing many miles of upturned slates and graywackes of uncertain age (Chapter X, and Figs. 89, page 180, 127, page 295). A stretch of fifty miles deserves careful structural determination, and the area in the immediate vicinity of Jisu Honguer would repay special study in Palæozoic stratigraphy. Permian fossils were recovered during the first season. In the second season, a map of part of the area was prepared, and a larger collection of fossils was made. The Permian beds extend far toward the southwest from Jisu Honguer, beyond the limits of the map. The Permian beds are overlaid by conglomerates of uncertain age, which we supposed to be Jurassic.

GENERAL PROBLEMS

There are, of course, many general problems not to be solved by study of a special locality, but which become more and more understandable as observations accumulate over a great region. Some of these are:

The study of both recent and more remote changes of climate.

The major steps in physiographic history.

The problem of peneplanation and the correlation of many planation remnants and partial planation effects, such as those on the sediments, and similar effects on the crystalline rocks.

The means or method by which the very perfect Gobi planation was accomplished.

Origin of the thousands of hollows that have no outlet.

The question of whether the wind has been as great a factor in erosion as water.

Evidence which the Gobi region offers on the problem of isostasy.

The part played by volcanism in deformation. Is it cause or effect; or are volcanism and deformation only incidently associated?

The reason why the region has changed so strikingly in its deformation habit since Jurassic time.

The age and history of the graywacke-slate series.

What evidence is afforded as to the life history of a bathylith?

What was the Palæozoic history of the Gobi region?

What was happening in the Gobi region in Pleistocene time?

The date of man's appearance and his reaction to the conditions of the region.

One of the most unproductive epochs in the first reconnaissance was the Pleistocene. Most of the Gobi seems to have been subject to erosion in that period. The life of that time had little opportunity to register itself by burial in accumulating sediments. But if the Gobi was characterized by erosion, there must be other regions, perhaps beyond the margins of our preliminary search, where sediments were being laid down. If one could discover where these are still preserved, better fortune ought to reward search for evidence of early man. Better conditions, we think, may prevail both farther south and farther east, and perhaps also along the disturbed margin of the Altai Mountains.

This opinion seems to be strengthened by the recently reported finds of the two Jesuits, Père Emil Licent and Père Teilhard de Chardin, who have discovered implements and dwelling sites of primitive man in Pleistocene beds of the Ordos, south of the Gobi. Reference has been made to these discoveries, and also to the primitive stone implements found by the Expedition, in Chapter I of this volume.

PART IV

SUMMARIES AND DISCUSSIONS

PART IV—SUMMARIES AND DISCUSSIONS

INTRODUCTION

THE chapters included in this portion of the volume are devoted to summaries, discussions, interpretations, and generalizations based on the observations and data gathered from the various fields and traverses whose more detailed descriptions have been given in the preceding chapters. In the following chapters, we attempt to correlate, explain and unify some of the results of the exploratory work of the Expedition in so far as this seems to be possible at the present stage of the investigation. This step is undertaken despite the fact that active work still continues with every prospect that modifications of the present understanding will grow out of subsequent work.

The purpose is not to state a final conclusion, but rather to outline those allowable inferences and generalizations which seem to be best supported, in the belief that in this form they not only are more useful in prosecuting our own future work, but will be of greater service to others.

With this purpose in mind, and with this explanation, we feel justified in presenting certain of these problems in a more definite form than would otherwise be warranted. They are the problems that have appealed to us and on which observations have been made which should lead at least in the direction of their solution. Whatever the answer may be, this evidence and these arguments will be taken into account, and we trust that additional contributions of our own in this direction may some day be added.

In studying the data on which these statements are made, we have worked with as much discrimination as we possess; and in reasoning from the assembled and assorted facts, we have tried to avoid all unfounded speculation. As is usual in geology, there are fields in which facts are scarce and data too limited for fully establishing any final conclusion; but where such is the case, we have tried to indicate it by a clear statement of the limitations. The purpose, therefore, has been maintained, even in these portions, in a form that we trust will serve as a record and as a suggestive discussion.

CHAPTER XVII

STRUCTURAL ELEMENTS OF THE OLDROCK FLOOR

DESCRIPTIONS have been given in several articles already issued (Berkey and Morris, 1924 *b* and 1924 *c*), as well as in preceding chapters of this volume, of the structural make-up of the rock foundations of the Gobi region. Portions of the published accounts fit our present purpose so well that it is considered appropriate to reproduce essentially the same discussion.

TWO MAJOR DIVISIONS

The most important single structural feature is the unconformity between the folded strata of comparatively ancient formations, which together make up a complex oldrock floor, and the nearly flat-lying sediments of Cretaceous and younger age, which lie above this floor.

Large areas in the Gobi region are covered with younger sediments that lie nearly flat (Fig. 10, page 53). The strata themselves are simple and, wherever they are disturbed, the deformation is of comparatively simple type also,—either gentle warping, or, somewhat more rarely, sharp flexure and normal faulting (Fig. 111, page 245).

In all other areas, much more complex rock formations are exposed, representing a more ancient floor which is doubtless continuous beneath all of the sediments. Wherever the old floor rocks are encountered, the type of deformation and the degree of internal modification exhibited by them are very different from those of the simpler overlying strata (Fig. 123). Everywhere the floor rocks are folded; in many places they are cut by igneous intrusives and notably metamorphosed. These features are, of course, more pronounced in the older members.

Wherever the rocks of these two very different types of formations—the sedimentary cover and the floor—are seen in contact, or where their structural relations can be determined, a great unconformity is found between them. The hiatus is so extensive that mountain-folding and erosion of thousands of feet of material were accomplished before the first basin sediments were laid down. Furthermore, it appears that during this interval an entire change in the diastrophic habit of north central Asia came about. Mountain-folding characterized the deformations that took place before that time, whereas warping and block-faulting, without mountain-folding, characterized subsequent epochs.

Late Mesozoic and Tertiary continental sediments carrying a remarkable new fauna constitute the formations developed above the unconformity. The rocks below, representing together all the ages preceding the Lower Cre-

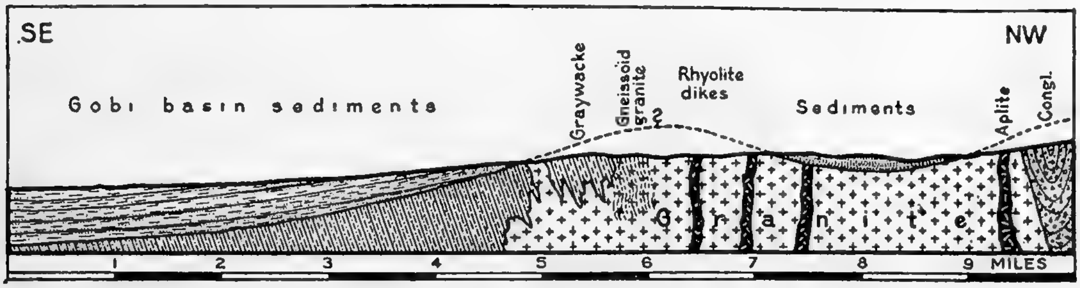


FIGURE 123.—Characteristic margin of a gobi sediment basin. This figure shows the upwarped, complex oldrock floor partly stripped but carrying small remnants of the former sedimentary cover lying on a nearly smooth erosion surface. This section represents a strip along the Sair Usu trail, about 400 miles northwest of Kalgan.

taceous, form the floor immediately beneath the younger sediments, and constitute the present surface in other parts of the region. The overlying sediments are at best but a thin veneer with many interruptions, and the dominant structural foundation for the whole of Mongolia is the ancient rock series below the great Mesozoic unconformity.

Traces of the peneplane developed at that time still form major elements of the topography, and surprisingly large tracts of this old floor are to-day entirely bare. Many of the bare areas have been covered at one time or another by later sediments, only to be denuded subsequently to some of the minor warpings of Tertiary time. In the more elevated areas, of course, agents of erosion, working toward a new level, have dissected this old surface, leaving only upland remnants of the former peneplane, whereas in well-protected areas, or those recently stripped of their cover, little change has been effected in all the intervening time.

SUBDIVISION OF THE OLDROCK FLOOR

From the great variety of rocks noted as belonging to the ancient floor, and the very great differences of physical condition represented by them, it is evident that this floor is of compound make-up. It has been possible to distinguish several sharply defined series of sedimentary strata, other more obscure metamorphosed formations, and yet other definite igneous units. In some cases there are prominent structural breaks between them, or the formations have structural relations characteristic of important differences either in age or in origin. Some are strictly igneous types of large extent and evident structural importance; some, on the other hand, are profoundly metamorphosed and have taken on all the complexities which commonly characterize the crystalline gneisses and schists of very ancient time; still others are only moderately affected by such modifying processes, and consequently are regarded as of much later age, corresponding in some degree to their greater simplicity.

At least six great groups are thus distinguished, some of which are capable of additional subdivision (Figs. 124, 130, and 161, page 415). This is

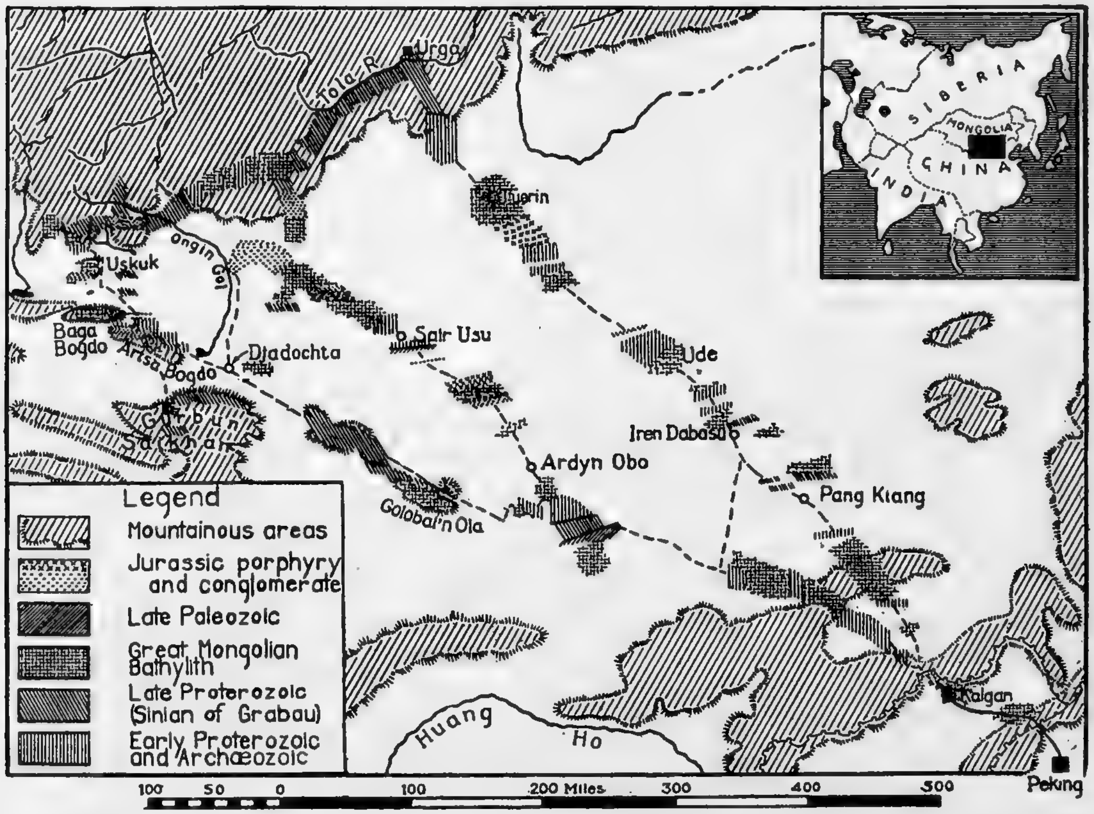


FIGURE 124.—Sketch map of Mongolia, showing the general geology of the rock floor along the route traversed by the Expedition.

true particularly of the lowest, most ancient one, where for present purposes all the strongly metamorphosed units are grouped together. These major groups, in descending order, are as follows:

6. Mesozoic porphyry intrusives and extrusives, cutting all formations up to and including the sedimentary series involved in the last folding of the region previous to the development of the great Mesozoic unconformity.

5. A great series of folded conglomerates and sandstones of continental type, considered to be chiefly of Jurassic age.

4. Strongly folded, fossiliferous Palæozoic strata of marine origin.

3. An extensive underlying and invading mass of granite, described as the great Mongolian bathylith.

2. A very thick and widely extended series of folded, unfossiliferous graywackes and slates, older than the granite bathylith and only moderately metamorphosed. We have called this the Khangai series, and tentatively consider it to be of late pre-Cambrian age.

1. Still more ancient, underlying complex groups of quartzites, slates, phyllites, schists, gneisses, crystalline limestones, and other associated metamorphic rocks. This complex is undoubtedly made up of more than one series. The upper members are judged to belong to the division distinguished in China as the Wu T'ai system, and the oldest members are regarded as local representatives of the T'ai Shan complex.

Mesozoic intrusives

A great variety of porphyries, forming dikes and irregular intrusive bodies of much larger extent, have been seen at many places. In some cases, at least, they cut the latest sedimentary series preceding the great unconformity. This clearly establishes the fact that they are the youngest of the formations of the ancient floor. The strata above the unconformity are regarded as of earliest Lower Cretaceous age, whereas those immediately below are judged, on rather obscure grounds, to be Jurassic. These intrusives, therefore, must also be of Jurassic age.

Representatives of this group are widely distributed, and in many places exhibit a formidable complexity of relations. So many different units are

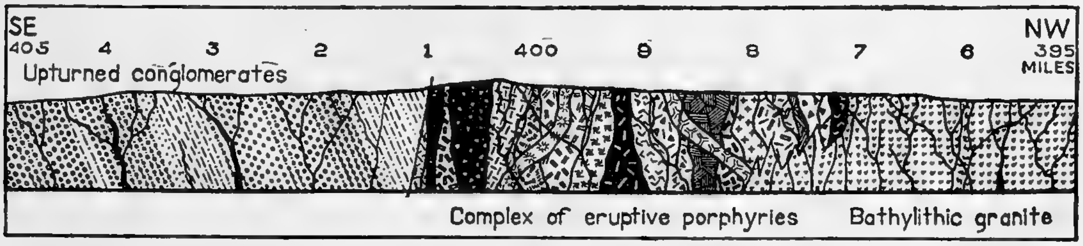


FIGURE 125.—Typical structure section of the oldrock floor. The section is based on ten miles of route traverse, seventy to eighty miles southeast of Sair Usu, on the Uliassutai trail. Folded Jurassic conglomerates, cut by many dikes, are seen at the left. A complex of eruptive porphyries occupies the center. The porphyries are invaded and undercut by the granite of the great Mongolian bathylith, which fills the right-hand end of the section. The ancient peneplane is remarkably smooth in this district, despite the complexity and variation in quality of the rock floor.

represented, and they cut one another in so irregular a way, that in certain areas they form a veritable igneous complex (Fig. 125).

Field investigations since the original article was published indicate that there are yet other ancient porphyry complexes, and that large areas are occupied by them. The porphyry problem, therefore, is a more difficult one than was at first thought. A discussion of it in the light of the newer observations, however, must await a later volume.

The commonest type is an acid porphyry, ranging in minor character from a simple quartz porphyry to granophyre and granite porphyry of comparatively massive habit. Intermediate composition is common also, especially trachytic or syenitic porphyries, and occasionally there are more basic types; so that the compositional and structural range is very wide. The most constant characters are fine grain, dense texture, and only moderately porphyritic habit. These rocks are brittle and exhibit a very broken condition, due apparently to deformation. This physical condition, together with the great irregularity of form and occurrence as part of a confused complex, is not so strikingly exhibited by any other series of rocks.

Wherever such an igneous complex intrudes the Jurassic strata, the original sediments are entirely displaced and none of the original structural trend is preserved. Areas represented by such rocks, observed at several points, cover many square miles. The best examples are those seen at Tsetsenwan, at Sain Noin, in the Mount Uskuk district, in the Artsa Bogdo range, on the Sair Usu trail east of the Ongin Gol, and on the trail southeast of Sair Usu. It is worth noting that igneous activity of a somewhat similar sort is prominent in China also, in association with exactly the same sorts of sedimentary formations. The type is constant enough in character, no matter how widely the porphyry areas are separated, to warrant the belief that some very widespread general source for these intrusions must have existed, operating under regional rather than local control. We are inclined to the belief that the active history of the great granite bathylith, in spite of its much greater age, is in some way connected with the genesis of the Mesozoic intrusions. There are certain differences of habit in the intrusives that appear in one age after another, that make the whole lot look like a genetic succession, as if they all, from beginning to end, represented only different stages in the active history of a single great, slowly differentiating, and repeatedly rejuvenated bathylithic mass. Perhaps these peculiar porphyries are only the normal product of particular stages from the master source (Fig. 161, page 415).

Jurassic sediments

The youngest of the sedimentary groups forming the old floor is a great series of conglomerates and sandstones of continental type, simply folded or in some places block-faulted, and quite free from important metamorphism (Figs. 125, 126). A large proportion of the material is coarse-grained, and considerable thicknesses are strictly conglomerates. Other great thicknesses are simple, well-bedded sandstones. Locally, interbedded finer sandstones are abundant, but as far as noted there are no large developments of shale or limestones. Nowhere is there any evidence of marine conditions. The entire series consists of stream deposits. The only fossils seen are plant remains, chiefly stems, which are poorly preserved. In certain portions of the series, however, there are thin beds of coal of low grade. Even in the coaly layers, the original fossil forms are nearly destroyed by deformation, so that the fossil content has proved thus far to be quite inadequate to determine the age of beds.

The material of the sediments is largely quartzose, or at least very siliceous, and the forms of the fragments indicate much wear. The three striking features are the enormous thickness of the series, its wide distribution, and the abundance of quartz pebbles and grains.

The rocks were found at several widely separated localities, the principal ones being at Camp Jurassic, fifty miles north of Ude (pages 67 and 280); at Tsetsenwan, one hundred and twenty-five miles west of Urga (page 103); at Sain Noin, three hundred miles west of Urga (pages 124 and 219); in the Mount Uskuk region, forty miles north of the Altai Mountains (page 228); in the Artsa Bogdo range (page 150); on the trail midway between Sair Usu and Ardyn Obo; and at a few other spots where the evidence was insufficient to determine the extent and local importance. There is evidence that strata of this series formerly extended over a much greater area than that covered by the Expedition.

Almost everywhere the strata stand on edge, or are strongly folded (Fig. 125); in some localities they are mashed and faulted, while a few synclinal remnants show little disturbance (Fig. 126). The total thickness in the district where this point could be best determined is no less than 25,000 feet, and at several other places great thickness is indicated, although estimates were not made (Figs. 40, 41, page 107). Doubtless the same series of strata forms

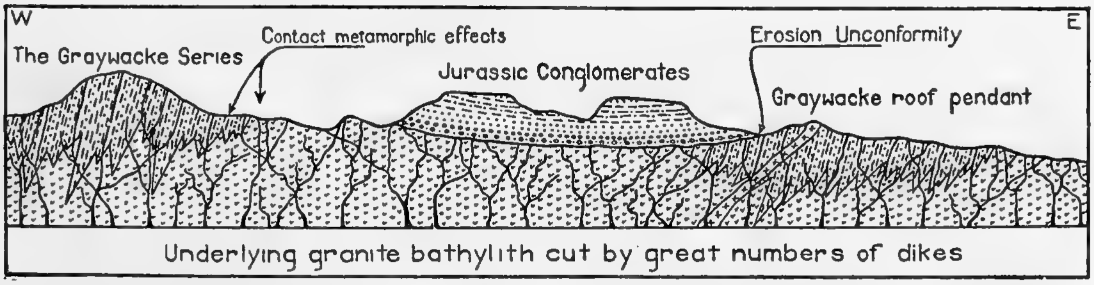


FIGURE 126.—Geologic section north of Tsetsenwan. A synclinal remnant of Jurassic conglomerates and sandstones rests uncomformably upon the graywackes and upon the bathylithic granite with its myriad dikes.

the floor beneath the covering of simple sediments at many places, but it appears that erosion has cut so deeply into the geologic structure of that time that only the lowest portions of the synclinal folds and the bases of fault blocks are preserved.

The whole series is pre-Cretaceous and precedes the general planation. On the other hand, it lies above another unconformity, the exact position of which in the geologic scale is undetermined except that it belongs above the latest Palæozoic sediments. The series, therefore, is apparently mid-Mesozoic and in all essential respects is analogous to and in many important features similar to the Lower Jurassic formations of China proper. The fossil evidence for age determination is inadequate, but no fossils other than plant remains are found either in the Mongolian conglomerate or in the Jurassic of China, and there are enough points of similarity in type of sediment, character of content, and deformation history to warrant tentative assignment to the same age. On this basis we are referring to the series as wholly of Jurassic age, although there is no good evidence against the presence of representatives of the Triassic also. In any case, the series must be regarded as a unit in which the only breaks of consequence are those marked by the igneous intrusions described under the preceding heading.

These intrusions occur at so many places where they are associated with the Jurassic sediments directly, that one is impressed with the necessity of accounting in some way for the close association (Fig. 125). It may well be that the deformation that accomplished the foldings and faultings of Jurassic time was occasioned by igneous activities in the depths beneath, one expression of which is marked by the intrusives. Down-faulted blocks, therefore, or very deep down-foldings may mark the places of weakness which guided the outbreak, and thus the sedimentary remnants and the associated intrusives are now preserved together. Other higher portions were more successfully removed by erosion.

Palæozoic strata

It is a most striking fact that all the sediments thus far found in central Mongolia, from the present back to the break at the close of Palæozoic time, are of continental type. But beneath the unconformity, at the base of the so-called Jurassic sediments, there is a great series of strata of marine origin, carrying abundant and characteristic fossils (Fig. 127). They include basal sandstones of only moderate development, with much greater thicknesses of limestones and shales preserved in down-folded remnants. Several thousand feet in thickness have been seen, but the total or maximum thickness is unknown.

Strata of this age have thus far been found in only two areas, both southeast of Sair Usu. The Tertiary faulting, which raised the modern Altai ranges, did not extend into this portion of the desert, so that the folded Palæo-

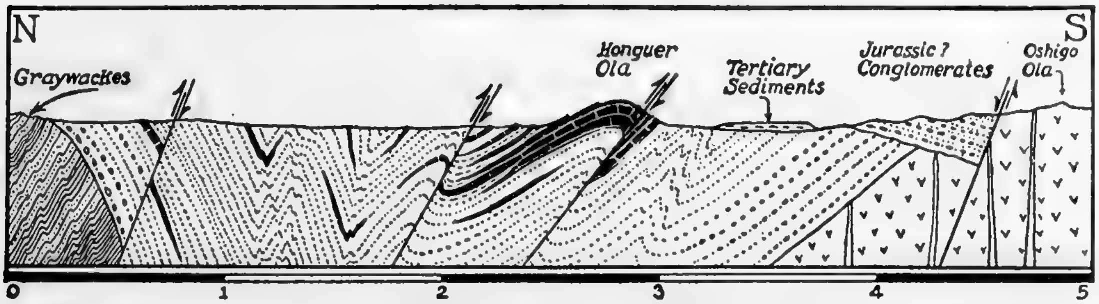


FIGURE 127.—Geologic section of an area of marine Permian beds at Jisu Honguer on the Uliassutai trail, about 330 miles northwest of Kalgan.

zoic strata have not been uplifted and are still simply part of the peneplaned floor (Figs. 78, page 171, and 89, page 180).

The larger proportion of the strata is judged by Dr. A. W. Grabau, from fossil collections made during the first season of the Expedition's work, to be of Permian age, but there is a continuation downward into a still earlier period, at least into the Pennsylvanian. Curiously enough, no representatives of these strata were identified in the Altai Mountains themselves, in either the Artsa Bogdo or the Baga Bogdo district. A single pebble carrying fossils of Palæozoic age was found loose on the northerly flanks of the Gurbun Saikhan. It therefore seems probable that representatives of Palæozoic age are to be found somewhere to the south in that region. Probably marine Palæozoic strata were formerly extensively distributed in this central Asiatic region, but the early Mesozoic or mid-Mesozoic epochs of diastrophism and erosion wrought such havoc that now only a few remnants are preserved.

The rocks are all closely folded, but the fossil content is fairly well preserved. The strike is nearly east and west, conforming in this respect to the average structural trend of the other elements of the ancient floor. Nowhere have we seen the exact relations between this series and the Jurassic above or the graywackes below. But the relative position in the scale can be inferred, and the general nature of the relation is reasonably well determined by differences of structural habit and physical condition. An important break is clearly indicated between the Palæozoic sediments and the Jurassic series, since the former are marine, whereas the Jurassic beds are strictly continental.

It is especially disappointing that the Palæozoic beds have not been seen in direct sedimentary contact with the graywacke-slate series beneath. This leaves some uncertainty about structural relation and relative age. It is clear that the graywackes are older, and, in view of the fact that they are unfossiliferous, more metamorphosed, and of an entirely different petrographic habit, we are inclined to believe that the graywackes are much older and are probably separated from the Palæozoic strata by an unconformity as pronounced as either of those above. There is abundant evidence that the great Mongolian bathylith, described as the next unit under the following heading, is later than the graywacke series and is very much older than the Jurassic sediments, which in some places lie on an erosion floor of granite (Fig. 126). But it is not entirely clear, from any relation yet observed, whether the Palæozoic sediments are younger or older than the maximum invasion stage of the bathylith. All the early and mid-Palæozoic strata are missing, so that there are no representatives yet found from Cambrian to Mississippian time. Apparently the Palæozoic era is the most defective one, as indicated by the few sedimentary remnants still preserved. The Palæozoic rocks mark a transient marine history between two very long epochs of continental control.

The great Mongolian bathylith

Between the sedimentary series just described and the older ones to follow, there developed in central Asia a granite bathylith, exposures of which can be seen at many places over a very large territory (Figs. 125, 126, and 128). The formations existing at that time, including the Archæan crystalline rocks and the graywacke-slate series, are invaded by the granite, and at many places where subsequent erosion has been deep enough, remnants of these earlier formations are preserved as roof-pendants. The granite appears as large areas of massive rock, and also as smaller intrusive masses, even dikes, which cut all the formations up to and including the graywackes. It is not so clear what its relations are to the Palæozoic series, but in one place the Palæozoic strata appear to rest upon granite with the normal sedimentary contact (Fig. 127). As the Permian beds near the contact are not metamorphosed, and as no granite dikes are seen cutting them, it seems fair to infer that the Permian sediments are younger than the granite.

It is possible, of course, that even the later intrusives, such as those which cut the Jurassic series, are products of the same great bathylithic magma; but, if so, they belong to a much later stage in its own development than that represented by the large areas of true granite (Chapter XXII, page 408). The stage of maximum invasion, in which the massive granite was formed, is probably pre-Pennsylvanian, and is certainly later than the Khangai graywacke. It is entirely possible that every igneous unit in the region, no matter what its age, is genetically connected with this immense bathylith. Its early developmental stages may have been responsible for the injection phenomena of the ancient gneisses; its maximum encroachment was attained in Palæozoic time, and its minor rejuvenations during old age may be recorded in the outbreaks of later periods (Fig. 161, page 415).

The granites show considerable variety of composition and minor habit, but the dominant type is a biotite granite of medium coarse texture and massive structure. It has produced an extraordinary variety of end-product effects and considerable contact metamorphism. Its relations, distribution, and special features are made the subject of a separate paper already published (Berkey and Morris, 1924, *a*).

The Khangai graywacke series

An extensive series of graywacke sandstones and interbedded shales or slates is widely distributed in Mongolia. It forms the major composition of the mountains of the Arctic divide, and constitutes the country rock of the Urga-Tola River-Tsetsenwan region, as well as the Khangai mountain range through the province of Sain Noin toward Uliassutai (pages 82, 90, and 122). The rocks are well exhibited in the Gurbun Saikhan (page 258) and in the small mountain tract twenty miles east of the Mount Uskuk block (page 227), as well as in the Ude region along the Urga trail (page 61). Representatives of the same formation are found in many other areas.

In the Tola River region and at Tsetsenwan and westward, graywackes predominate, whereas southward and eastward we find a greater proportion of interbedded shales. Neither the top nor the bottom of the series has been determined, but it is certain that it is of very great thickness,—probably at least 20,000 feet.

As far as observed, the strata are unfossiliferous throughout. Diligent search was made for possible fossil content, and, in the hills east of Mount Uskuk, slates were found with obscure markings that are believed to repre-

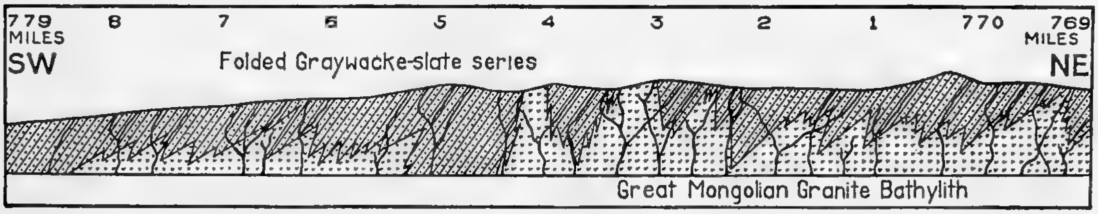


FIGURE 128.—Typical geologic section of the Khangai series. The section lies one hundred miles southwest of Urga. Simply folded graywacke strata are undercut by the great Mongolian bathylith and are locally metamorphosed by contact influence.

sent imprints of some simple organic form, probably algæ. A few thin, limy lenses contain tubular structures which may be borings made by some wormlike animal. A striking thing, of course, is the unfossiliferous nature of these rocks in spite of their simple sedimentation structure, in strong contrast to the richly fossiliferous habit of the Upper Palæozoic strata. It is not believed possible that the graywackes and slates, with their splendid bedding structure and abundance of original shales, could be of Palæozoic age without bearing better evidence in the form of fossil content.

We are well aware that the graywackes farther north and east are regarded as of Palæozoic age by Russian geologists, who report fossils from certain localities. In the Gobi region covered by our own traverses, however, we have not found any determinable fossil content in the graywackes, and these rocks are more modified than are the recognized Palæozoic strata. The Carboniferous strata begin near Sair Usu, above a basal conglomerate, instead of making a transition to the graywacke series. At Jisu Honguer, both the graywacke series and Palæozoic strata are present, but again there is a structural break between,—this time a fault instead of a transition.

As we interpret the ground at Jisu Honguer, the Palæozoic strata belong to a down-faulted and crowded block which brings the two formations side by side. In physical habit, as well as in surface form, they differ greatly. It is our purpose to make a special study of this problem at a later time. Under these circumstances, we think that the evidence still favors more ancient correlation for the graywacke series, and we regard all of the Palæozoic rocks as down-folded and down-faulted remnants of superimposed strata of a later age.

Dr. J. Morgan Clements (1922), working north and northeast of Urga in the Kentai Mountains, found graywackes which he considered pre-Cambrian. This is doubtless our Khangai series. Ussov (1915) has recorded his opinion that the graywackes of the Kentai are Algonkian. In view of the difficulties in the way of correlating this formation and the widely divergent views regarding it, we are inclined to let it stand as probably pre-Cambrian.

Siliceous limestones of dark gray to blue color are found associated with slates in some localities; they also are quite without fossils so far as we have seen. Probably the limestones represent incursions of a shallow sea, and the very fact that they lack fossils so completely suggests that they are pre-Cambrian. The graywackes are probably non-marine and of the same age, and, especially in the Khangai Mountains and the region about Urga, where limestones are quite lacking, it is believed that the great series is essentially continental.

Everywhere the series is folded. In places where it is made up largely of original shales, there is much internal deformation, so that typical slates have been formed, but wherever the much more massive graywackes predominate, simple folding is more common, with very little internal deformation or metastructure.

The series was invaded by the granite bathylith subsequent to its folding, and in many places over extensive areas the graywackes and slates now form the only roof. Great numbers of dikes cut through the series, and the surface of the bathylith itself is very uneven, so that after prolonged erosion, patches of granite are exposed, alternating with patches of graywacke (Fig. 128). In places where the granite lies close beneath, considerable contact metamorphic effects have been produced on certain qualities of the graywacke-slate series. In some places a crystalline condition and moderately schistose structure are thus exhibited, whereas normally the rock is plainly granular and not schistose.

THE ANCIENT CRYSTALLINE COMPLEX

Clearly older than the graywacke series, as indicated not only by their structural relations but also by the much greater metamorphic modification, is a great group of formations which doubtless includes several different series, but which together may be conveniently referred to as the ancient crystalline complex (Fig. 129). The simplest of the rocks of this class are slates, phyllites, schists, limestones, and conglomerates that are clearly derived from

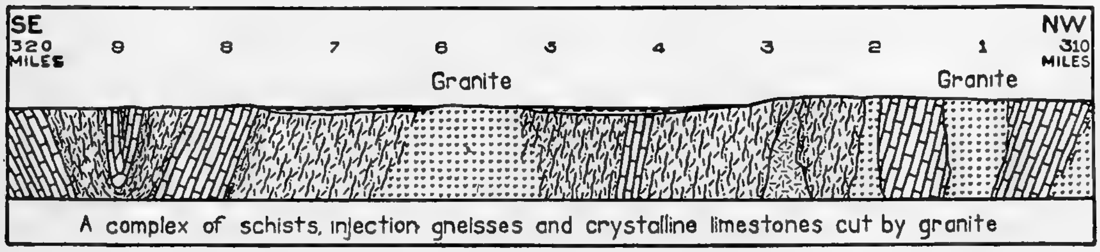


FIGURE 129.—Typical geologic section of the most complex pre-Cambrian rocks. This section lies nine to nineteen miles northwest of Sair Usu, on the Uliassutai trail. The mountain structures have been peneplaned, and bear two very shallow basins of later sediments.

some ancient sedimentary series, of much more variable habit and somewhat different origin from that of the overlying graywacke series. They stand everywhere on edge; they are repeatedly exposed in many places as widely separated as are the observations of the Expedition. There are few places, however, where they cover extensive tracts, and fewer still where many different members of the series are exposed together.

The Wu T'ai system

Because of the fact that in certain places conglomerates are found in the midst of these series, and on account also of an observed difference in the degree of metamorphic complexity of certain members, we think the evidence favors the existence of at least two great systems of pre-Cambrian rocks, older than the rocks of the Khangai graywacke series.

If we are right in regarding the graywackes as pre-Cambrian, they must be late pre-Cambrian, and as such they should correspond approximately to the Nan K'ou series of von Richthofen (1877), and Hu t'o system of Bailey Willis (1907, II, page 7), in China, or the Sinian system of Grabau (1922). Our next older series in Mongolia may include the greenish chloritic schists in the Artsa Bogdo range of the Altai Mountains (Chapter XV, page 263). There is also a vast series of greenstones and chloritic phyllites in the mountains east of Ardyn Obo, which may be of igneous origin, and perhaps represent ash beds and surface flows that have undergone thorough reorganization (Chapter X, page 178). More data bearing on this problem may be expected when these rocks are studied with the microscope. Thin beds of limestone were found in the greenstone area. Mica schists and mica phyllites were seen on the Kalgan-Urga trail north of P'ang Kiang, and crystalline limestones are associated with them (Chapter III, page 55). The phyllite-schist-limestone-greenstone group outcrops at many places, yet is nowhere as thoroughly pierced and saturated by invading igneous material as is the group of rocks next to be described. In his "Research in China" (1907, II, page 4) Bailey Willis classified a series of phyllites, limestones, quartzites, schists, and greenstones under the Wu T'ai system, which he assigns to the early Proterozoic. We see no better classification for these very similar rocks in the Gobi region (Figs. 130 and 161, page 415).

The T'ai Shan complex

Still more complexly modified rocks are found in the Gobi region. They are largely gneisses, associated schists, and crystalline limestones. The gneisses range from granitic to dioritic in general composition, but they are not simple granites and diorites. They represent a complex in which the original rock probably was a schist. This original rock has been invaded by igneous material which has penetrated and saturated the original, following in the main the structural lines of the schist. The magma has replaced as well as penetrated the host rock, so that now the igneous matter is a streaked gneiss because it has inherited the structure of the schist which it has largely destroyed and replaced. Where the igneous streaks are less predominant, the rocks may still be classed as schists, and among these the commonest type is a coarse-grained muscovite-biotite schist, streaked with lenses and thin sheets of granite or pegmatite. The limestones are white to blue or gray crystalline marble.

Such rocks were especially noted in the block mountain south of Tsetsenwan (page 111); in another block mountain forty miles southwest of Tsetsenwan (page 114), and north of Kalgan on the road to the pass, as well as at many other places.

Because of the great complexity of structural habit, these rocks are regarded as still older than those we have referred to the Wu T'ai system, and,

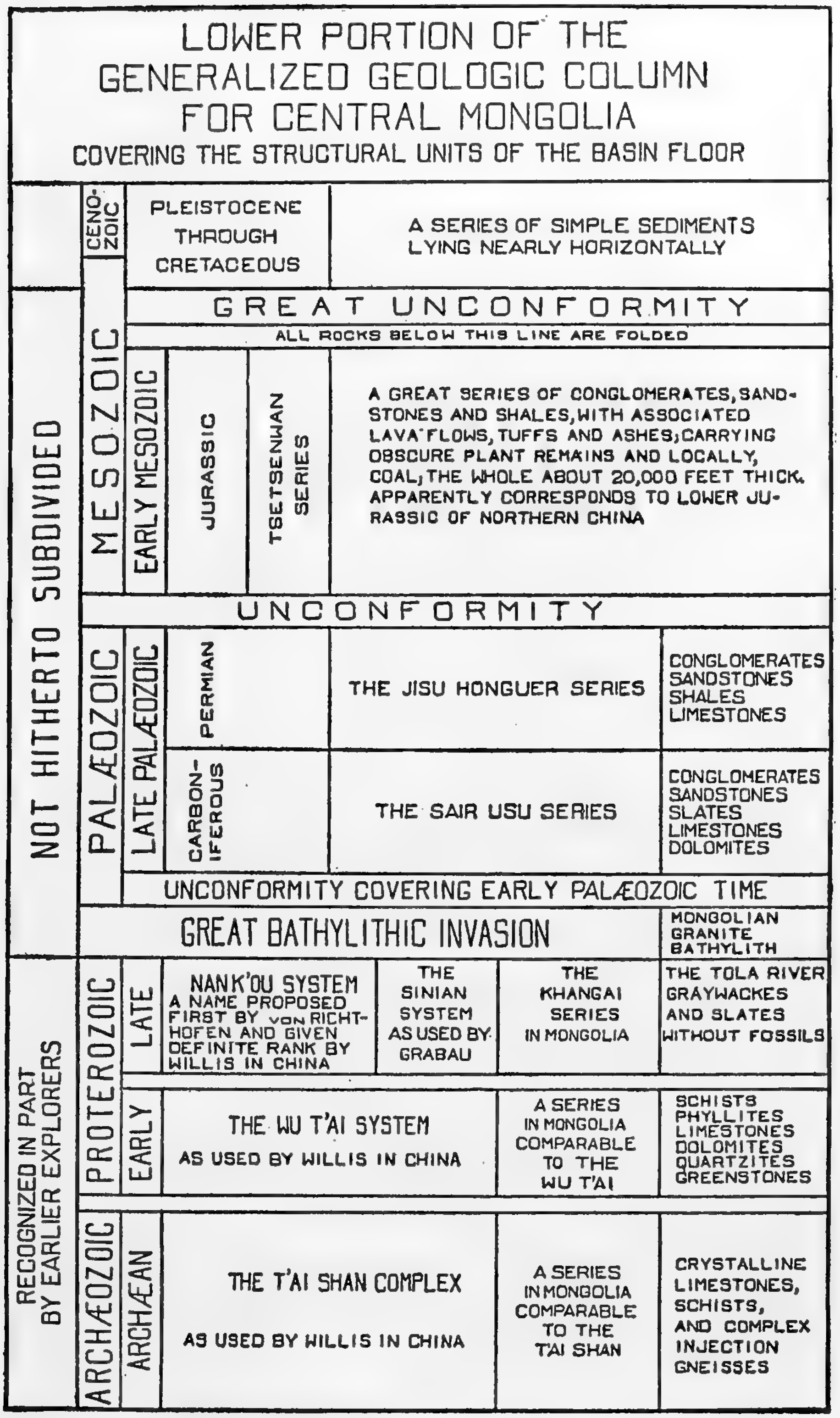
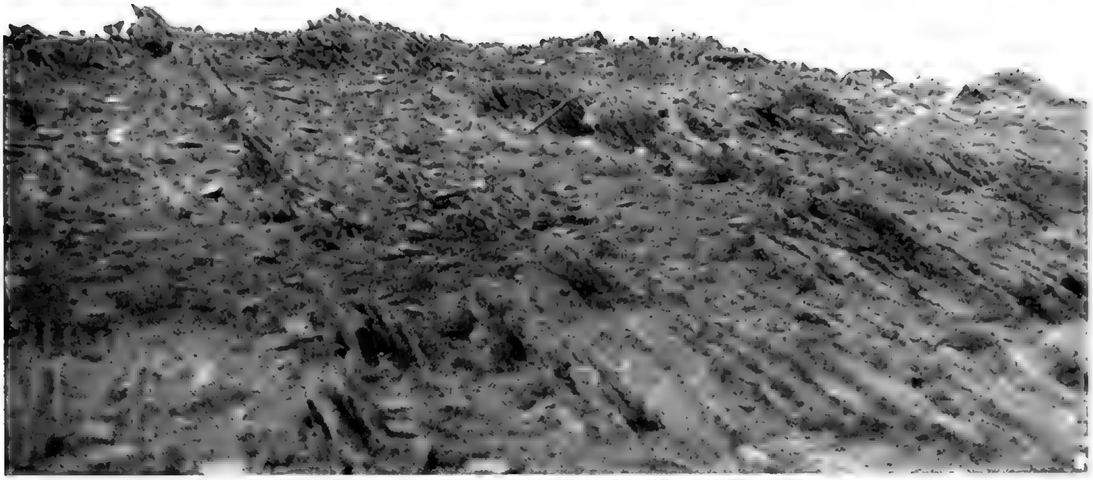


FIGURE 130.—Summary table of the formations of the oldrock floor.

again following the usage established by Willis in China, we regard these oldest of the formations yet seen in the Gobi as Archæozoic and equivalent to the T'ai Shan of China.

Undoubtedly there are great breaks between the principal members of the pre-Cambrian series. It is believed that the conglomerates seen on the Urga trail in the midst of these formations (page 80 and Fig. 27), and the conglomerates seen between Tsetsenwan and Sain Noin, two hundred miles west of Urga (Fig. 45, page 115), mark some of the important breaks, but even without these there is sufficient evidence in the differences of the rocks themselves to warrant such subdivision as has been made and such age differences as are indicated in the tabulation (Fig. 130). Doubtless very much greater detail of formational make-up is actually exhibited than has been determined as yet, but the major elements of the ancient rock floor and the major characters of the individual series are reasonably well expressed as a working basis by the accompanying table (Fig. 130).



A. BEVELED SURFACE OF UPTURNED PHYLLITES AT GORIDA.

The photograph is taken looking down on a nearly level surface.

B. SHATTERED GRAYWACKE.

Upturned and broken graywacke strata cut by a shattered quartz-porphyry dike, near Jisu Honguer.

PLATE XXXIX.

A. DEFORMED JASPERITE IN THE GRAYWACKE SERIES.

The photograph was taken near Five Antelope Camp, south of the Tola River.

B. THE PHYLLITES OF ARTSA BOGDO.

The fine, micaceous schists of Artsa Bogdo have a remarkably regular crumpling across the schistosity and bedding structures.

CHAPTER XVIII

SURFACE FEATURES AND THEIR ORIGIN

BASINS AND MOUNTAINS

THE BASIN OF MONGOLIA

AN inland basin of more than a million square miles lies enclosed between the Great Khingan range on the east; the Transbaikal, Kentai, Khangai, and Tannu Ola, on the north; the eastern ends of the Sayan, Sailugem, and Altai, on the west, and the Nan Shan system on the south (Fig. 131). The essential basin shape is well shown in Fig. 4, page 43. The minor basins, mountain ranges, isolated peaks and hills, and hollows containing lakes, playas or saltpans, which rise above or sink below the general sloping surface, do not disturb its basin-like character. Across these many and various surface features the Desert of Gobi is flung like a pall; it has no definite boundaries, but covers mountain, plain, and hollow.

Deserts in general

In a broad sense, a desert is any part of the land where plant and animal life are under notable disadvantage, so that only a sparse population of rather specially adapted forms can live. We may recognize three types of desert:

1. Deserts due to scanty rainfall.
2. High altitude deserts in lofty mountains.
3. High latitude or snow-deserts.

The Gobi desert, as the arid part of a great inland basin, belongs to the first class.

The shaping processes

The inland basin of Mongolia, like all other land surfaces, has been molded and carved by geologic processes of two types: the constructional processes which tend to build up or make a country, and the destructional, which tend to destroy rocks and lower the land surface. Under the term *constructional* are included:

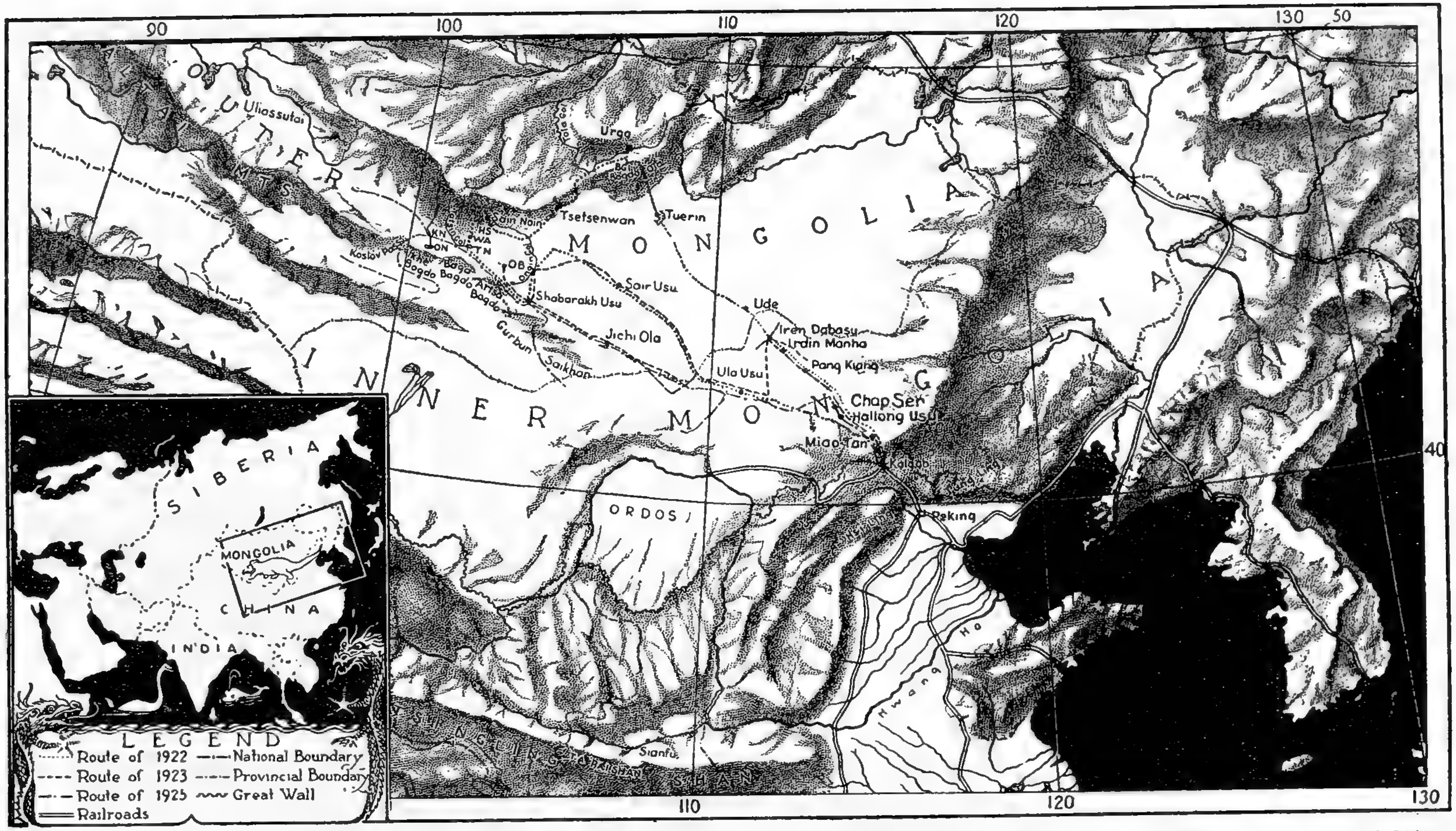


FIGURE 131.—Relief sketch map of Mongolia. Mountainous areas are shaded; lowlands are white. The basin form and relations of the plain of China, the lowland of Manchuria, and the Gobi basin of central Mongolia are shown. The basin of central Mongolia has no outlet but is separated from the Dzungarian basin, joining it on the west, and from the Tarim basin on the southwest by only low upwarped divides; the Manchurian basin is breached and extensively dissected; the plain of China is a delta plain, built out into a structural basin which dips beneath the sea.

1. Tectonic movements: warping, faulting, thrusting, folding, uplift.

2. Volcanism: the outpouring of lava, the ejection of ash, tuff, and bombs, and the building of volcanoes.

3. Sedimentation: a process which lies on the borderland between the constructional and the destructional.

In general, all sediments except volcanic ash and tuff result from the destruction of rocks by weathering and erosion. But those sediments which fill basins in the interior of a continent may be considered constructional, as they tend to build up the surface by means of new strata of rock which are as permanently a part of the continent as any other rock it possesses.

Accordingly, the constructional landforms in Mongolia will be the major and minor warped basins and their contained sediments which form the plains and plateaus; the mountain ranges and the volcanoes and remnants of volcanoes.

Destructional processes include:

1. Weathering: mechanical and chemical.
2. Erosion: the work of ice, running water, waves, and wind.

In the Gobi region, the mechanical processes of weathering are rather more active than the chemical. Temperature changes are abrupt and great, and frost action is vigorous. Quartzites, flints, jasper, chalcedony, siliceous argillites and other very elastic and brittle materials tend to chip, flake, and split when rapidly heated and chilled, so that the outcrops are commonly seamed with a network of fine cracks. Rocks which are composed of several different kinds of minerals tend to crack apart, yielding nearly unaltered crystal fragments. Thus granite, consisting chiefly of quartz and feldspar, breaks down into a coarse sand of quartz, feldspar, and granite chips, covering large areas of the rock floor. The surface of the granite bedrock is so disintegrated that it is difficult to obtain a fresh specimen. In addition to the vigorous mechanical weathering, there are also some chemical changes, for the ferromagnesian minerals are altered and rusted, and the feldspars are somewhat kaolinized. Basalts and other dark, igneous rocks split into blocks; unlike the granites, they do not break down into a sandy residue of fresh minerals, but alter chemically into clayey soils. The sudden changes of temperature have less effect upon the limestones than upon the more siliceous rocks, but their surfaces are commonly etched by the solvent action of rain water into a fretted pattern of shallow pits.

The chief erosional processes in a desert are the work of running water and of wind, and almost all destructional land-forms are due to their activity, although it is often very hard to tell which plays the dominant rôle. Glacial ice and the waves of lakes are both minor erosive agencies in the Gobi region.

Each of the factors will be discussed in connection with the land-forms which it helped to shape.

MAJOR SUBDIVISIONS OF THE MONGOLIAN BASIN

In Chapter II, we present evidence of warping and faulting in the bordering ranges of the Gobi, indicating that the vast, shallow depression enclosed by these ranges is essentially of tectonic origin. The earth movements were not uniform throughout the region, so that the inland basin of the Gobi may be divided into an eastern and southern warped province and a western faulted province. The warped province is a broadly open country in which extensive plains, underlaid by Cretaceous and Tertiary sediments, are separated by areas of low rolling hills of ancient complex rocks. The present topography is chiefly the result of warping and differential erosion. In the western province, block-faulting of the Altai type controls the major relief features.

Because of the unequal warping, each province is divided into a number of broad depressions which we have called "talas," from a Mongol word meaning an open, intermontane country. In the east and south, the talas are large, rudely oval, shallow basins; while in the Altai province, they are narrower and deeper, walled in by high mountains, and their surfaces are diversified by minor mountain ranges. Within each tala, there are many lowland areas filled with sediments, for which we adopted the term "gobi," as the Mongols told us that "gobi" is the name for the flat desert floors which we recognized as deposits of Tertiary and Cretaceous sediments. While the tala is a topographic element, the gobi is a lens-shaped mass of sediments, underlaid by the eroded and downwarped oldrock floor.

The talas of the eastern and southern province

The eastern and southern province of the Gobi falls into three great warped basins or talas, which we have called the Dalai, the Iren, and Gashuin talas, each from a lake lying in the deepest part of the depression. The Dalai tala is the one least known to science, and in the present volume it cannot be treated authoritatively, as the Expedition has never entered it. The northern part of its broad floor is occupied by a chain of lakes, some of which drain through the Argun River to the Amur. South of the lake region lies a rougher country which is apparently a continuation of the oldrock hills of Chakhar. The most recent explorations have been conducted by the Jesuit Fathers, Teilhard de Chardin and Emil Licent (1924 *c*), who, after traversing a considerable area of the oldrock hills, discovered abundant Pliocene fossils in a series of sands, clays, and marls, which are overlaid by lava flows. They also report a "chain of Quarternary volcanoes extending more than one hundred kilometers." (Teilhard, personal communication, 1924.)

The divide between the Dalai and the Iren talas is a broad swell of the oldrock floor, dissected into many low ranges which, according to the maps, strike nearly east and west (Fig. 131). The main axis of the arch lies rudely parallel to the Khingan range, and may have been formed at the same time and by the same processes of warping which uplifted the Khingan.

The Iren tala was traversed by the Expedition in 1922, and part of it was restudied in 1923 (page 198). It is a broad, open country, unmistakably higher everywhere than in the center about Iren Dabasu, for which our barometer readings recorded an altitude of 2,930 feet. From this general low center, the tala surface rises gradually northward to about 6,000 feet at the Arctic divide, and southward to about 5,000 feet at the Pacific divide. Probably at least half of the area of the tala, judging from what we have seen, is occupied by gobi-basin sediments resting upon a floor of older complex rocks. It was here we first recognized that a single tala may carry many gobis of widely diverse size and age. Thus, in the seven gobis crossed between Kalgan and Urga, sediments were found ranging from Lower Cretaceous to at least Pliocene age. The sediments are beveled by a remarkably smooth surface which we named the Gobi erosion plane (Chapter XIX, page 332). Undrained hollows are excavated below this level surface, and many of them contain small salt lakes. The Iren tala lacks an integrated drainage more completely than does any other tala as all streams are short and drain radially into the hollows. The gobis are separated by low ranges of maturely dissected hills composed of ancient complex rocks, whose upland is crowned by a well-developed erosion surface which we named the Mongolian peneplane (Fig. 147, page 342).

Obruchev (1901, II, page 434) crossed the desert from the Yellow River to the Gurbun Saikhan range, along the very boundary between the Iren and the Gashuin talas. He reported outcrops of the oldrock floor throughout almost the entire route, but noted one area of very smooth desert which we take to be a gobi.

The Gashuin tala forms the southwesternmost part of the warped province and extends, indeed, west of some of the typical faulted talas. It is pierced by faulted ranges on the west, and bounded by faulted ranges on the north, thus marking the transition from the warped to the faulted province. Gashuin Nor is the largest of a group of lakes lying in the lowest part of the depression and receiving from the Nan Shan and Lung Shan ranges a withering and dividing stream called the Edsin Gol. Very little is known of the geology. Chernov (1908) visited the region but gives little more than a geographical description of it. He says, however, that there is good evidence that the lakes and rivers were once larger than they now are, indicating a recent change in climate toward greater aridity.

The western faulted talas

The talas of the western region are much smaller than the warped talas of the eastern and southern province. They are bounded by faults on at least one side, and, according to Suess (1902, III, pages 132, 135), some parts are reported to be true grabens, enclosed between faults on both north and south. In another paper (1924 *b*) we have called them the Tsagan, Shargin, Kisin, Kara, Kirghiz, and Ubsa talas. Only one of these, the Tsagan tala, has been visited as yet by the Expedition. Klementz (quoted by Suess, 1902, III, pages 122–125) has described the basins of the "Valley of the Lakes," which we have called the Kara, Kisin, and Ubsa talas, as a succession of steps, like the treads of a great stairway, descending northward from the Altai front to the Ubsa tala, which lies only 2,660 feet above sea level at the foot of the Tannu Ola. He says that the depressions are separated by faults or faulted ranges.

The Tsagan tala lies between the Khangai arch on the north, and a series of overlapping ranges of the Altai system on the south (Fig. 131). Like the Iren, the Tsagan tala illustrates strikingly the fact that a number of gobis, carrying sediments of very diverse age, can be contained within a single tala. At the foot of Baga Bogdo lies a gobi about thirty miles broad, between the Altai front and the Uskuk block (Fig. 98, page 194). The sediment-fill includes Lower Cretaceous, Oligocene, Miocene, Pliocene and Pleistocene beds with a total thickness of about 10,000 feet. North of the Uskuk block is another beveled and redissected gobi which is far less warped and has a lower relief than the gobi to the south. At one point we found reptile bones, indicating that at least some of the beds are Cretaceous. North of the chain of saltpans that occupy the deepest part of its concave surface, the gobi ends against the rock shelf that rises steadily into the great swell of the Khangai Mountains. As we go eastward to Artsa Bogdo and again plot a section northward, the mountain front descends abruptly to a gobi consisting of sediments and lava flows, all more or less disturbed by faulting and tilting and exposed in the eroded walls of several large hollows (Fig. 118, page 269, and Plates XXXV and XXXVI, page 268). The only fossils found indicate a Lower Cretaceous age. The sediment-basin extends far to the northward beyond our reconnaissance.

East and somewhat south of the Artsa Bogdo, lies the Gurbun Saikhan range. The basin north of it is more gently warped than either the Artsa Bogdo or the Baga Bogdo piedmont basin. Diversified by desert hollows and oldrock inliers, and cut through by the river valley of the Ongin Gol, the smooth surface of this gobi extends over one hundred miles to the northward, ending, like the others, at the foot of the Khangai arch. At three widely separated places where the geologists reached the mountain, the basin sediments were seen steeply upturned against the front of the range. At least three distinct formations have been recognized in this gobi: (1) the thick Lower Cretaceous Ochungchelo formation, probably of the same age as the Oshih, is exposed at the foot of the middle range of the Gurbun Saikhan; forty miles to the northwest, another thick formation, the Dubshih, believed to be also of Lower Cretaceous age, underlies the Djadokhta sands. It is as yet impossible to say whether the Dubshih and the Ochungchelo are of the same age; (2) the Djadokhta formation carries a Cretaceous fauna quite different from that of the Oshih; and (3) the Gashato formation bears a very primitive mammalian fauna and has been tentatively called Paleocene.

These brief descriptions omit much detail, but with their aid one may form a mental picture of a faulted tala,—a structural basin with a very complex history of warping, faulting, sedimentation, erosion, and occasional volcanism.

MOUNTAINS

Bounding the Gobi, and partly included within it (Fig. 131), are some six groups of mountains that represent but two general classes: (a) tectonic mountains; (b) volcanic mountains, which are of very minor importance in Mongolia.

To the tectonic class belong: (1) the Khingan range, which lies nearly athwart the Altai trend, striking about 26° east of north; it is probably upfaulted along the eastern front, while its western face slopes gently into the Gobi basin; (2) the Baikal-Yablonoi group, which consists of relatively short, broad, fault-block mountains, controlling a special type of drainage pattern in which the rivers seem to be adjusted to fault lines and grabens; Obruchev (personal communication, 1925) writes that they are peneplaned blocks, and that the valleys are tectonic and bear fills of Tertiary sediments which are being eroded by the present rivers; (3) the Khangai-Kentai group, which consists of broad, gently upwarped masses of peneplaned mountains, now deeply dissected; faults are present, but, in the main, they do not control the drainage, which is essentially of dendritic pattern; these three types are considered in more detail under the heading "Boundaries of the Gobi" (Chapter II); (4) the Altai group of long, relatively narrow, fault-block ranges, which trend about east-west in gently curving, parallel lines, enclosing strips of desert lowland between them; (5) the older ranges in the warped province, consisting of low, maturely dissected hills.

Fault-block mountains of the Altai type

The Altai belongs to a great group of ranges between the Khangai and the Tien Shan. All, including the Tien Shan, are essentially long, narrow fault-blocks extending nearly east and west and enclosing broad, intermontane basins (Fig. 131). They form the most important mountain system of central Asia, and their structural features and history are characteristic of the deformations which have taken place in this region since the beginning of Lower Cretaceous time. We saw four ranges of the eastern Altai,—Ikhe Bogdo, Baga Bogdo, Artsa Bogdo, and Gurbun Saikhan, named in order from west to east. In the same order, they diminish in size, Ikhe Bogdo being the highest of the four. A touch of primitive poetry in the Mongols has led them to name many of their finest mountains after their gods: thus, Ikhe Bogdo means the Greater Buddha; Baga Bogdo, the Lesser Buddha; Artsa Bogdo, the Buddha of the Trailing Junipers; and Gurbun Saikhan, the Three Fair Ones.

In general form, the eastern ranges are typical examples of the long, narrow Altai fault-blocks. They overlap one another as shown on the map

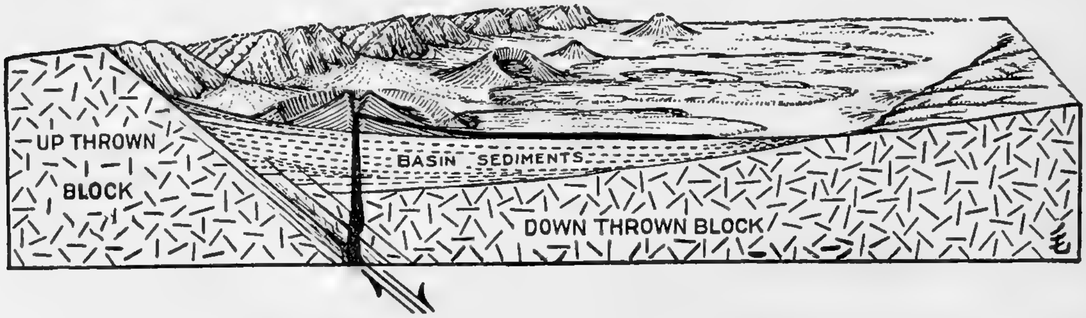


FIGURE 132.—Generalized block diagram of a faulted basin. This diagram represents a rectangular block sliced out of the earth. The front of the block shows the cut edges of the rock structures. The center of the block is represented as the down-sinking area where sediments have continued to accumulate as deformation progressed. The uplifted portion, stripped of its original cover, ultimately forms a long, straight, mountain front of old crystalline rocks more or less deeply dissected by continued erosion. Volcanic eruptions have taken place along the zone weakened by faulting. This feature of the diagram represents conditions that existed in Cretaceous and Tertiary time rather than the present, for the volcanic cones have been destroyed by later erosion; but lava flows and ash-beds are still preserved, interbedded with the sediments. The latest development is an overspread of alluvial fans along the mountain front.

(Fig. 98, page 194.) The northern front of each rises steeply to a crest which lies but a short distance behind the base line. From the crest we saw that the whole top of the range is a sea of nearly accordant peaks, which we judged to be a peneplane. In most of the ranges this upland surface tilts gently downward toward the south. In Artsa Bogdo and Baga Bogdo, and probably in Ikhe Bogdo, the southern face is notably lower than the northern, and drops steeply to a broad lowland. In each lowland, but especially in the northern basin, sediments have accumulated, associated with lava flows (Fig. 132).

Ikhe Bogdo.—Concerning Ikhe Bogdo, Suess's summary of Klementz's reports (Suess, 1902, III, page 134) indicates that the range is narrow, that it is made of granite and some schists, and that the northern slope is extremely steep and difficult. In 1922 we saw from a distance that the range has a remarkably smooth upland surface, or peneplane, and that the heads of the major valleys are cirques, recording the easternmost glaciation in the Altai system. At the foot of the range lies a broad piedmont basin. We visited the range in 1925 and observed so many special features that a separate description will be required. This will appear in a later publication.

Baga Bogdo.—The range is about fifty miles long from east to west, and not more than twelve miles wide from north to south. Its position is indicated on the sketch map (Fig. 98, page 194). From Mount Uskuk, forty miles north of Baga Bogdo, the surface of the piedmont basin slopes downward into the depression of the lake Tsagan Nor, and then gently rises 2,000 feet to the foot of Baga Bogdo. From this slope, the mountain juts up more than 4,000 feet, attaining an altitude of nearly 12,000 feet above the sea, and a height of about 7,000 feet above Tsagan Nor. The summit peneplane slopes gradually from the east and west ends of the range, up to the culminating twin peaks near the center (Fig. 106, page 224). The stream valleys that dissect the mountain front at this point are so short and straight that, standing in the mouth of Tiger Canyon, one can clearly see the two peaks, 4,000 feet above, yet less than three miles away. As we climb the valleys, they open through terrace after terrace. The lower benches are narrow and relatively modern, and correspond to several stages in the history of the alluvial fans. But the higher shoulders, 2,500 feet and more above the inner gorges, are remnants of much wider and more mature valleys which have been almost wholly destroyed by later dissection. They must mark earlier stages in the growth of the range, when the mountain, much lower than it now is, had paused long enough in its uplift to develop a network of broad valleys.

The range is made entirely of ancient, complex rocks of diverse kinds and ages, but it is a significant fact that the folding and the granite intrusions were accomplished long before the uplift of the present fault-block range began (Plate XXX in pocket)

The alluvial fans are of extraordinary interest, as they contain part of the record of mountain growth and part of the record of the climatic changes of the region. There are at least four series of fans. The oldest is the Pliocene Hung Kureh formation which outcrops less than five miles north of the mountain, and consists chiefly of thin-bedded clays and fine sands. The modern streams bear coarse gravels far beyond the northern scarp of the dissected Hung Kureh. It is, therefore, probable that the mountain was lower when the Hung Kureh beds were deposited. If the range had been as high as it now is, the accumulation of fine pond clays so near the mountain would not have been possible, as the average slope of the present piedmont surface is more than 200 feet per mile. The Hung Kureh beds are tilted and even somewhat folded, indicating that mountain-movements have crowded them since their deposition. Upon the Hung Kureh lie the rubbles of the Gochu fan, which have been tilted so that their bedding planes dip as much as 20° southward toward the Altai front, quite reversing the original dip (Fig. 107, page 229). They bear a record of deposition followed by tectonic movement, followed in turn by prolonged erosion before the third fans were laid. The third, or high fans, overlie and partly bury the eroded remnants of the Gochu fans, but even they have been so dissected that some of the cones have been almost wholly cut away, leaving remnants that now stand 300 feet and more above the modern fans. The remnants connect with a rock terrace in the mountain valleys, below which the modern streams have cut deep trenches. The dissected fans record a long period of accumulation, followed by a reversal of conditions and the removal of vast amounts of material. The fourth and most recent series of fans has been built in the gaps torn through the older fans, and is chiefly of later date than the cutting of the inner trenches of the mountain valleys. The modern fans also record changing conditions: first, the piling of gravels along the mountain front in the canyon mouths and in the broad gaps torn in the older fans; then a dissection of these fans to a depth of 150 feet. At the mouth of Tiger Canyon, terraces are cut in the modern fan (Plate XL, B, page 388), which indicate balanced conditions, when the stream widened its bed without greatly deepening its channel.

The record demands very careful reading because effects of mountain growth may sometimes be confused with the results of climatic change. During dry cycles, when the protecting vegetation of the mountain slopes withers and the streams disappear shortly beyond the canyon mouths, the soil and loose rock wash down and overload the streams, which pile the burden along the mountain front, building up the alluvial cones. But during rainier epochs, living roots form a thick mat which blankets the mountain slopes, holding the soil in place so that the rivers are not overburdened, while their actual supply of water is increased. With increased water and diminished load, the streams begin to excavate their channels and to dissect the alluvial fans which they had piled up. Uplift, with the steepening of all gradients within the mountain, tends to rejuvenate the streams and push the alluvial fans farther out into the piedmont lowland. A long pause in the uplift permits the streams to lower their gradients and so to increase the fans which previously they had piled up against the mountain front. Uplift, therefore, works a result similar to that of a moist climate, while the effect of a period of quiescence in mountain growth resembles that of a change to a dryer climate. Where the fans are not only dissected but tilted, which is true of the Hung Kureh and the Gochu fans, the fact of disturbance in geologically recent time is plain. In the case of the two later series of fans, where there is no change of dip and no direct evidence of renewed faulting, a change in climate seems to be the most rational explanation (page 390).

Artsa Bogdo.—Artsa Bogdo is notably lower than Baga Bogdo; the highest peak thus far reached stands about 8,000 feet above sea level. The northern front juts up steeply from the smooth piedmont slope to an upland surface which rises gradually and as gradually descends toward the south. Notable monadnocks stand above the upland peneplane. The southern face of the range is less steep than the northern front. Within the mountain block most of the streams have a dendritic arrangement, although a few subsequent streams have developed along belts of weak rock. One well-marked terrace borders the valleys and broadens upstream until it becomes the valley floor, and the younger, inner gorge disappears. In the high valleys, which are broad, richly grassed meadows, herds of big-horn sheep and ibex graze side by side with the sheep, goats, and yaks of Mongol drovers. The slopes are beautifully decorated with the spreading rosette growth of the artsa or juniper, which gives the range its name. There are thus four topographic elements within the range: (1) the steep-sided inner gorges of the lower valleys; (2) the terraces and high meadows in the upper valleys; (3) the summit peneplane; and (4) the monadnock peaks rising above the peneplane (Fig. 116, page 264). To these might be added two exterior surface elements,—the front slopes of the range, and the smoothly eroded rock shelf or pediment, at the foot of the mountain (Fig. 114, page 261).

Like Baga Bogdo, the range is composed of an uplifted block of complex rocks—schistose conglomerates, schists, limestones—with large and small intrusive masses, chiefly granites and diorites. Infolded or infaulted in the oldest rocks are slates, sandstones, and conglomerates which we tentatively assigned to the Jurassic. At the eastern end, the crystallines disappear beneath a great field of lava, probably Jurassic or Lower Cretaceous (page 262).

Only a portion of the history of the piedmont basin at the Artsa Bogdo range is known (Fig. 114, page 261). Along the northern front there is a narrow but distinct pediment, which bevels the same hard rocks that compose the mountain. The slope at the foot of the mountain front is an erosion plane, and, as at Baga Bogdo, the modern alluvial fans are relatively small. The rock waste issuing from the mountain is carried through the beveled basin sediments in stream courses which are trenched well below the erosion plane. Each stream valley bears a terrace, coated with a heavy layer of partially cemented coarse conglomerates. The piedmont slope is locally varied by mesas, capped with black basalt. The tilted conglomerates seen at the foot of Baga Bogdo are absent.

Twenty miles north of the range, a thick deposit of Lower Cretaceous sediments is exposed in the scarps about the Oshih hollow. Between the Oshih and the Artsa Bogdo the rocks are for the most part covered. Close to the northern face of the range, however, unfossiliferous sediments are exposed and steeply upturned, indicating that they once extended farther. Along the southern flank of the mountain lie red and gray sediments with reptile bones of the Oshih fauna. We consider it probable, therefore, that the present site of the Artsa Bogdo range was covered by Oshih sediments in the Lower Cretaceous, and has been uplifted and cleared of sediments since that time. So, the peneplane on the top of Artsa Bogdo might well be the ancient floor on which these sediments were laid down; in this case, it would be a stripped or resurrected peneplane. The more conservative view is that the upland level is part of the later Mongolian peneplane, for which we have tentatively proposed an early or middle Tertiary age (1924 *d*).

A brief summary of the history of Artsa Bogdo, so far as it is known, is as follows:

1. A complex mountainous country was peneplaned during or before Lower Cretaceous time.

2. The Oshih sediments were deposited upon the old floor in Lower Cretaceous time and covered certain low monadnock ridges of the old hard rocks. Volcanic activity accompanied the deposition of the sediments, and possibly there were outpourings of lava after the sedimentation was completed.

3. The region was disturbed by faulting and tilting, which were renewed at intervals. Some of the resting periods were so long that the relief features, due to faulting, were planed away. The upland peneplane of Artsa Bogdo, the broad terrace along the valleys in the mountain, and the planed rock shelf at the foot of the range, are records of the larger intervals of quiescence and erosion.

Gurbun Saikhan.—The Gurbun Saikhan is not a unit, but a broad mountainous area including a number of nearly parallel ranges, separated by long, relatively narrow depressions. The Mongols have given names to the three chief blocks—the Baron Saikhan, the Dzun Saikhan, and the Dunde Saikhan, meaning the Western, Middle, and Eastern Good One. To these should be added a smaller but structurally similar ridge along the northern front of Baron Saikhan, and a long block extending southeast of the Dunde Saikhan.

Each is a long, narrow, steeply rising uplift, essentially like the other eastern Altai ranges, and each is composed of old complex rocks. In the Baron Saikhan, we observed silicified and partly replaced limestone, large intrusive, stock-like masses of serpentine and diorite, and steeply folded argillites, slates, and graywackes (page 256). In the front range, we noted a younger series of argillites and graywackes, and an older series of phyllites, chloritic schists, and sheared, schistose conglomerates. The Dunde Saikhan consists wholly of one closely folded series, including graywackes, slates, siliceous argillites, and green, dense, silicified ash, the age of which has not been satisfactorily determined.

The front of each range rises sheer from the piedmont slope, without any foothills. There is an upland peneplane, which is tilted and bent at various angles in the several ranges. Above it stand higher monadnock peaks. The southern slope of Dunde Saikhan is much steeper and higher than the northern face, reversing the rule for this part of the Altai system. Within each range, the valleys are terraced, and the cutting of a younger, narrow, winding gorge has destroyed the terraces near the mountain front; but deeper within each range, the upper parts of the valleys open into gently sloping, beautiful meadows, affording rich pasturage and unfailing water.

Along the foot of the Dunde Saikhan, two series of alluvial fans are displayed. The older fans are sixty to a hundred feet higher than their modern successors, and have been much dissected. In places, they have buried the mountainous topography of the front range, and the entrenched river valleys are superposed across the hard-rock ridge and have cut gorges through it. The detritus that forms the younger fans is led in channels through the remnant of the dissected high fans and is spread out on the long, smooth piedmont slope, thinning gradually until the underlying basin sediments of Cretaceous and Tertiary age again form the surface.

The history of the Gurbun Saikhan must be read in part from the ranges themselves, and in part from the record of the surrounding sediments. Tilted and faulted Lower Cretaceous sediments have been seen along the northern and southern fronts of the ranges. At the foot of Dunde Saikhan, they must be nearly 2,000 feet thick, and consist chiefly of evenly bedded clays and fine-grained sands. At the Baron Saikhan, red sands and conglomerates without fossils are upturned to a dip of 78° upon the front of the mountain (Fig. 113, page 257). Along the low front range a dip of 56° was recorded. The sediments were formerly more extensive and may well have covered the site of the present ranges. The Djadokhta sands, consisting of almost pure silica (page 356), could not have been derived from the Gurbun Saikhan oldrocks by simple decay and transportation, but must have been derived from an older, sandy sediment that had already been considerably assorted. This inference suggests that the oldrocks of the Gurbun Saikhan were not exposed during the accumulation of the Djadokhta sediments (Fig. 133). The first sediment in which the fragments of the oldrocks appear prominently is a gravel of angular pebbles, overlying the Djadokhta (Fig. 133, C). The gravel forms the base of the Gashato beds, which consist of variable sandy clays, sands, and gravels, which may have been derived directly from the weathering of the Gurbun Saikhan.

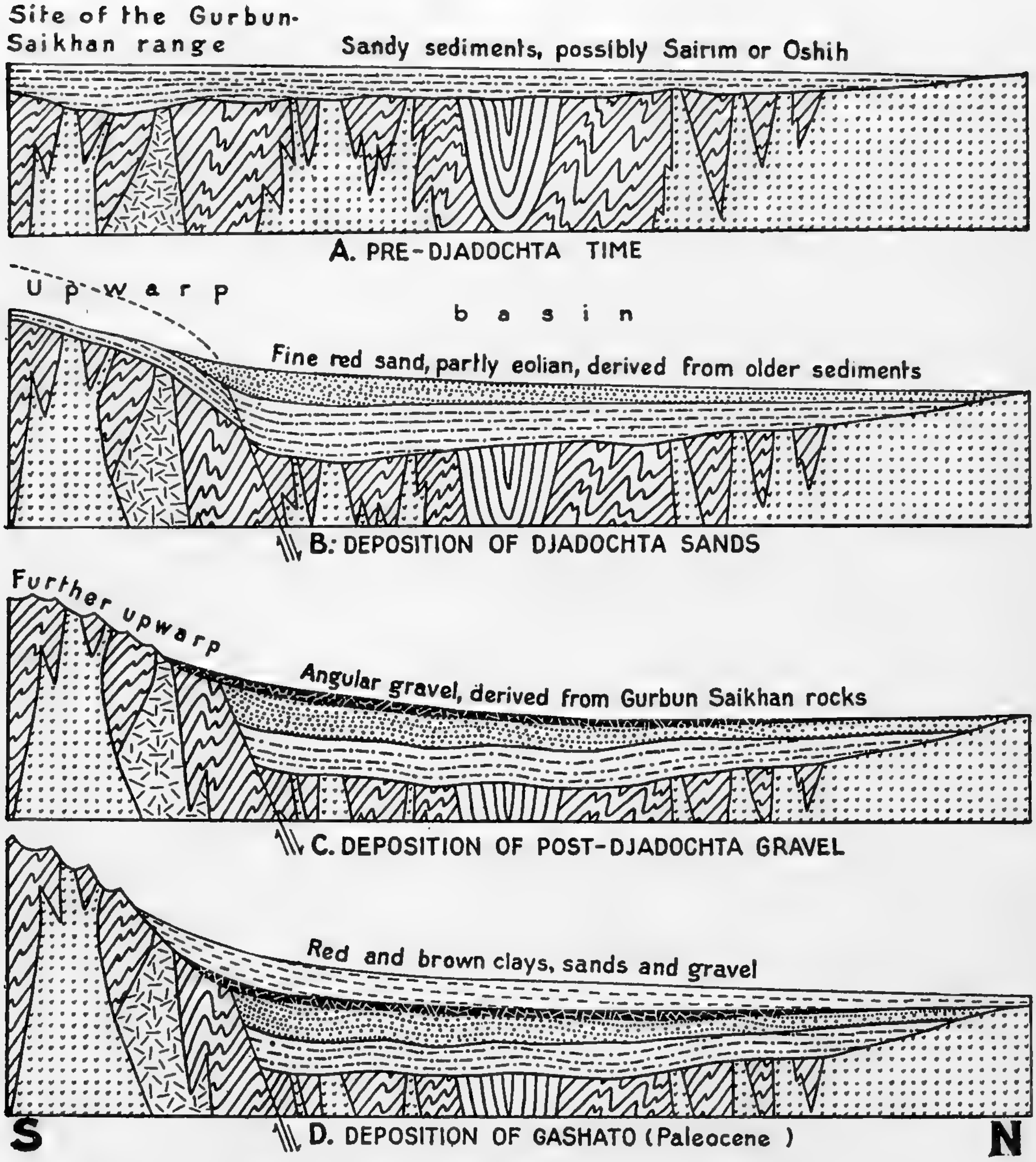


FIGURE 133.—Four stages of warping and sedimentation at the Gurbun Saikhan:

A shows a cover of Lower Cretaceous sediments resting on a complex oldrock floor.

B shows initial upwarp of the Gurbun Saikhan range and corresponding deposition of the Djadokhta sands.

C shows renewed upwarp and deposition of angular pebbles from the newly exposed Gurbun Saikhan rocks.

D shows the deposition of the Paleocene Gashato beds.

Subsequent to this last stage there has been renewed deformation and extensive erosion, and alluvial fans from the mountains are now encroaching upon the remnants of all three formations.

The history of the Gurbun Saikhan may be summarized as follows:

1. A complex mountainous country was peneplaned prior to Lower Cretaceous time.

2. Basin-making began in Lower Cretaceous time, and the site of the Gurbun Saikhan was covered with sediments (Fig. 133, A).

3. There followed a period of quiescence, indicated by the break between the Lower Cretaceous and the Djadokhta formations.

4. Warping began again, and material derived from the older basin sediments was carried into the new basin to form the Djadokhta beds (Fig. 133, B).

5. Slight warping and disturbance took place.

6. A period of quiescence and erosion continued through most of Upper Cretaceous time. During this interval, a new erosion plane was carved upon the Djadokhta beds.

7. Probably in Paleocene time, warping and uplift were renewed, and the Gurbun Saikhan oldrocks were laid bare; the Gashato formation began with a wash of gravels derived from the mountains; clays, sands, and gravel followed, and at least one lava flow tells of volcanic activity (Fig. 133, C, D).

8. Uplift of the mountain continued with faulting. The latest faulting may be as recent as we judged it to be at Baga Bogdo, i.e., early Pleistocene.

9. The range has been vigorously redissected by the streams of at least two cycles—an older stage marked by a terrace in the river valleys, and a younger, indicated by deepening and gullying.

The mountains of the eastern province

No ranges of the Altai type were seen in the Iren tala and none is reported from the Dalai tala. As a typical example of the mountains of the warped province, we may describe the hills of Chakhar along the Kalgan-Urga trail (Figs. 7 and 8, page 51). The range extends for about fifty miles, east and west, and is about twenty miles wide from north to south. The highest altitude is somewhat less than 5,500 feet above sea level, and the upland stands not much more than 1,000 feet above the general desert surface. The splendidly developed Mongolian peneplane (Fig. 147, page 342) crowns the summits, and has been very maturely dissected. In some of the valleys which are as much as six miles wide, there are shallow accumulations of sediment which bear Pliocene and Pleistocene fossils (Andersson, 1923 *a*). There is no doubt that the range stands as a monadnock mass above the lower level of the desert, but the age of the monadnock remains a problem for future study. There are two possible explanations of its origin: it may be a peneplaned remnant of a mass that was upwarped or faulted during early Tertiary time (in this case the weathering away of the mountains furnished the sediments now retained in the surrounding gobis); or it may be a disinterred monadnock which was formerly buried under the sediments which lie north and south of it. We are inclined to favor the first interpretation.

There are many such masses as the Chakhar Mountains, especially in the eastern talas. In general, their history seems to be very simple. They are probably fault-blocks or broadly arched domes, which, since the time of their uplift, have been so thoroughly eroded as to destroy all the diagnostic signs by which we might recognize their precise mode of origin. An example of a disinterred monadnock is found in Oshigo Ola, which is a low granite ridge near Iren Dabasu (Fig. 134). It rises very gradually, less than 300 feet above the smooth, planed sediments that surround it. The oldest of these sediments

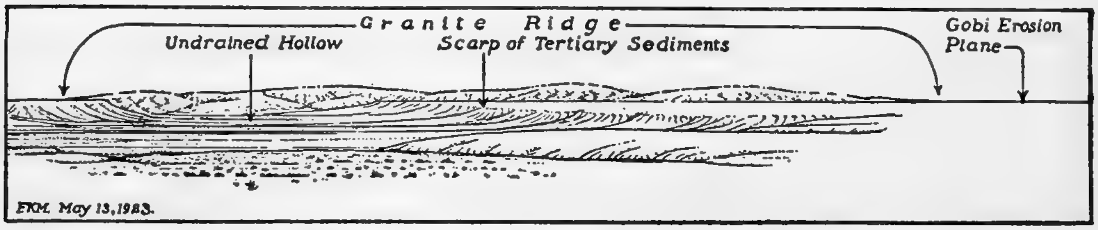


FIGURE 134.—Field sketch of Oshigo Ola, from the south. The low ridge of granite is being exhumed from the sediments which still partially bury it, and which have protected it from erosion since Cretaceous time.

are the Cretaceous Iren Dabasu beds, which outcrop some three miles north of the ridge. They are overlaid by Eocene strata, which show an undisturbed sedimentary contact with the granite ridge, for the beds are horizontal, and, as we follow them toward the ridge, there is a distinct increase in the amount of granite fragments in the sediment. Therefore, the ridge surely existed in Eocene time. The Cretaceous beds are not faulted, are only very faintly warped, and contain abundant fragments of granite waste. It is probable, therefore, that Oshigo Ola is not a post-Cretaceous fault-block but was a knob upon the oldrock floor when the Iren Dabasu beds were being laid down. It is still partly buried in sediments, and its preservation throughout Upper Cretaceous and Tertiary time can be explained only by supposing that it was buried during most of this interval.

Many other hills of hard rock rise through the gobis, and their history, if studied, would probably be very like that of Oshigo Ola. Two such exhumed monadnocks are shown in the sketch of the Oshih basin (Fig. 118, page 269). It is not impossible that some of the major ranges, such as parts of the Altai, may have chapters in their history that tell of burial and reexcavation, though in their case there is always a more extensive history of faulting and warping.

Volcanic mountains

Although in the Dalai tala, volcanoes with fresh cones are reported by Teilhard de Chardin (1924, *c*), no true volcanic cones were found in the territory covered by our Expedition. However, about one hundred and ten miles southeast of Urga, we passed two tiny, cone-shaped hillocks, not over sixty feet high (Fig. 25, page 79). They are covered by a rubble of spongy scorias, which, under the microscope, are found to be chiefly fused clay. For this reason, they should be considered as outlets of hot volcanic gases, a very special type of volcano. They probably are of Quaternary age.

In all other areas traversed by our Expedition, the volcanic cones that must have existed in the past have been worn away. Lava flows, which have been buried in sediments for several geologic periods, and upstanding dikes and necks were found at many places. For example, isolated black peaks were seen in the distance, from the vicinity of Camp Jurassic, west of the Urga trail, but were not visited. Their real character, therefore, is not known; but the fact that volcanic eruptive material is abundant, and that these hills lie along the projection of one of the major fault lines, seems to favor the conclusion that they are remnants of small volcanic outbursts (page 68; Fig. 18, p. 65). North of Djadokhta there is a sharp volcanic neck called Khurul Obo—the Bronze Peak—surrounded by many dikes and flows (Figs. 67, 68, page 159). Together they represent a volcanic center extending over fifty square miles. The original cone of Khurul Obo has been eroded away.

No laccolithic mountains have been reported by any observers in Mongolia.

THE STRUCTURE LINES OF MONGOLIA

By way of summary of the general relations of mountains and basins, it is well to review briefly the structure lines of the region; that is, the compass directions in which the following structural elements of the rocks lie: the cleavage-planes of gneisses, schists, and slates; the axial planes of folds; the strike of tilted rocks; the strike of fault-planes; the axial trend of mountain ranges and basins.

In Mongolia these structures can be considered in four classes: (1) Those of the oldrock floor of Mongolia; (2) those of the Tertiary fault-blocks; (3) those of the warped and faulted talas; (4) those of the gobis.

1. The trends of oldrock lines belong to two groups (Plate IV, page 22):

(a) A group with a general northeasterly direction, includes:

The Khingan trend, a little east of north, for the eastern ranges (von Richthofen, 1882, II, pages 520, 734).

The northeastward Baikal trend for Transbaikalia (Obruchev, 1899, and 1914) (Fig. 135).

The Sayan trends in the region west of Lake Baikal; they swing in a great S-shaped curve from northeast-southwest to northwest-southeast and back again (Suess, 1902, III, pages 90, 91, 102, 107).

(b) A group with a general easterly direction, includes:

The Altai trend, curving from southeastward to nearly east and west, for the region between the Tannu Ola and the Tien Shan (Suess, 1902, III, pages 111, 126, 132).

The Kuen Lun trend, swinging from 20° north of east to 15° south of east for the Richthofen, Nan Shan, and Tsingling Shan ranges.

The structure lines of the ancient gneisses and schists vary extremely. East-west lines predominate. In the region traversed by the Expedition, we

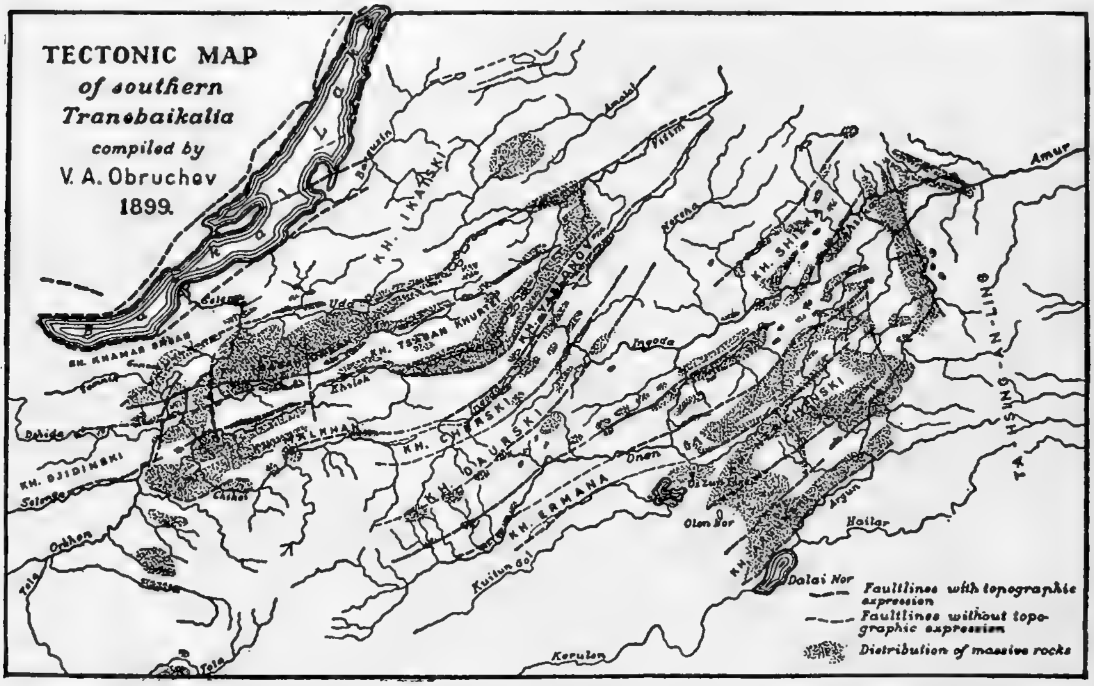


FIGURE 135.—Tectonic map of Transbaikalia (after Obruchev). The faults which mark the present ranges are drawn in heavy broken lines; areas of massive igneous rocks are shaded with short dashes. Faults of two trends are shown, the northeasterly Baikal trend and the northwesterly Khingan trend.

noted nearly north-south strikes at a few places, although in the main they follow the Altai trend, varying between N. 60° E. and N. 60° W. The strike of the latest pre-Cambrian graywackes varies also, but in most places it averages N. 70° W. Near Urga, the strike swings toward northeast as much as N. 40° E., approximating the trend of Lake Baikal. The Palæozoic rocks strike about N. 80° W., though N. 65° E. was observed near Sair Usu. The Jurassic folds are the least regular that we have seen, but even these vary, for the most part, within twenty degrees of the east-west line. Much more detailed study is needed before this system of folding can be reconstructed.

2. The faults of Tertiary and post-Tertiary ranges trend, in many places, at an acute angle to the direction of folding in the rocks which compose the

mountains, and there are oblique faults which divide the Altai into separate, overlapping ranges. But, taken collectively, all the Altai blocks form a series of somewhat arc-shaped chains, lying, as Obruchev has pointed out (1912, 1915), with their convexity toward the south. Granting all divergence from the structure lines of the older folding, there remains, through at least five mountain-making revolutions, a fair agreement between the old and the new trends. The repetition of trend in mountain-making revolutions which are

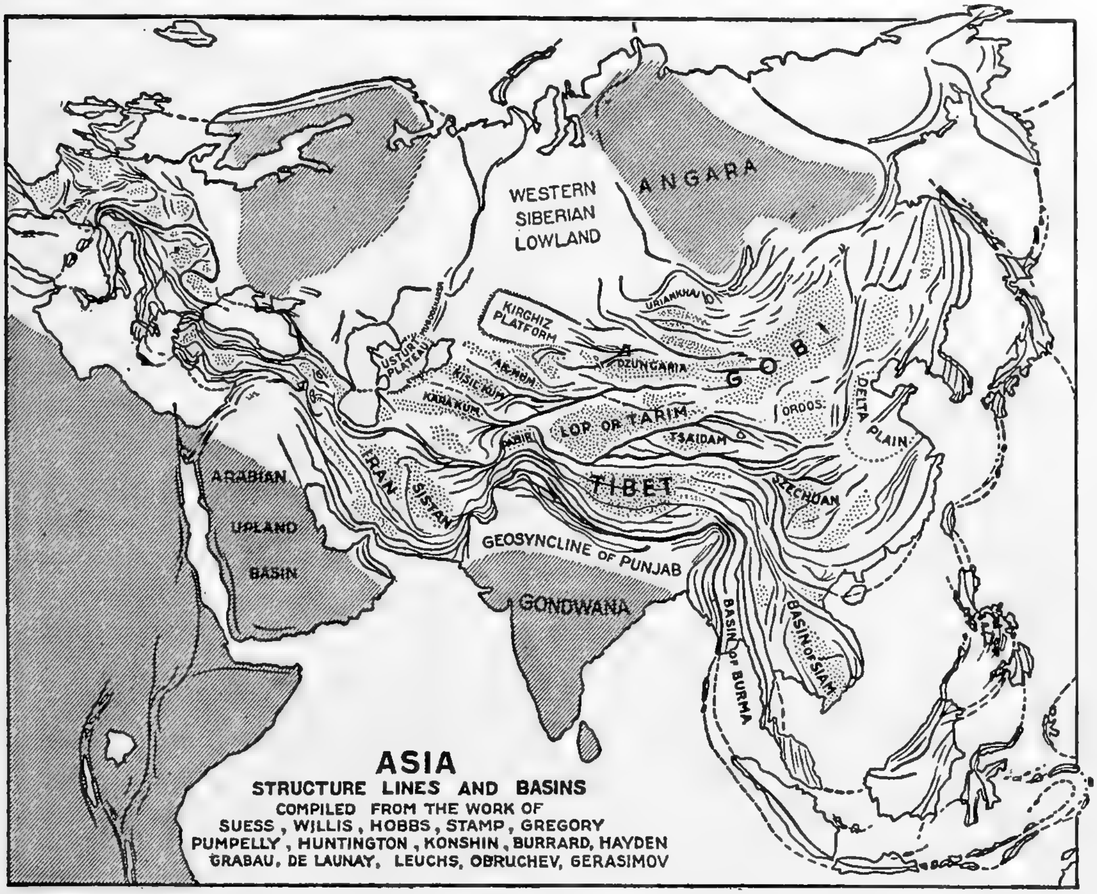


FIGURE 136.—General structure lines of Asia. The solid lines represent the trend of folded and faulted mountain ranges. The stippled areas indicate the great interior basins. The shaded areas represent the recognized positive elements.

separated by vast time intervals is also well shown in the Khingan range, where the ancient pre-Cambrian gneisses and the Tertiary arch lie almost parallel to one another, though this direction is nearly at right angles to that of the Altai ranges.

3. The talas of the faulted province are distinctly elongate east and west. The Iren tala is nearly round, and the Dalai tala's longer axis lies parallel to

the Khingan. Evidently the basins are controlled by the same regional tendencies of deformation that have upwarped and upfaulted the mountain blocks and inter-tala divides.

4. The gobis are less definitely outlined, but in those of more readable history and more suggestive form, it is clear that the east-west axis is the longer. In some cases at least, there is sharp flexing or minor faulting along the north or south margins.

The axes of the Cenozoic mountains and lowlands (Fig. 136) agree very nearly with the strike of the folded Palæozoic sediments and with the structure lines of the ancient schists and gneisses. The general agreement is far more striking than the local divergences. The folding, thrusting, and faulting that have made mountains, have followed much the same directions in successive revolutions since early pre-Cambrian times, indicating an orderly constancy of control in the earth movements that, throughout the immensely long sequence of sedimentations, foldings, and igneous intrusions, have welded together the continental elements that are now Asia.

CHAPTER XIX

SURFACE FEATURES AND THEIR ORIGIN (*Continued*)

PLATEAUS, PLAINS, AND FLATLANDS

INTRODUCTION—THE LEVEL LANDS OF THE DESERT

BETWEEN the mountains around and within the great basin of Mongolia, we journey across wonderfully smooth and level areas that have been called "plains" by travelers in the past. An examination soon shows that in one place the smooth surface is underlaid by granite (Plate X, B, page 60), in another place by folded slates (Plate XXII, A, page 183), in a third by tilted sands and clays (Fig. 111, page 245), and in others by horizontally lying strata of many kinds (Figs. 137 and 138). These flat surfaces are the result of erosion, but the granites and closely folded slates belong to ancient mountain structures which have been worn down, and only the horizontally lying strata come within the definition of the true plain or plateau. A plain is a region of horizontal strata, smooth, or dissected into low relief (Johnson, 1916, page 444). The plain and plateau differ only in that the plateau is carved into high relief. In Mongolia, the horizontally lying strata—either plains or plateaus—are found in the gobis, and therefore all the typical sediment-basins or gobis are true plains or plateaus, resting upon a foundation of complex mountain structures. They would be classed as plains throughout the open country of the large warped talas, where their relief is low—rarely exceeding 300 feet (Plate X, A, page 60). Deep dissection in the piedmont basins along the Altai has developed such rugged country in the sediments that possibly the term "plateau" would be appropriate there (Plates XXXV, XXXVI, page 268). The only term we used in the field for the horizontal or but slightly tilted strata was "plains"—because the areas of rugged relief are relatively small pockets of dissected badland country along the few stream valleys or around the walls of undrained hollows.

The erosion surfaces which bevel the gobis and the hard rocks cannot be called peneplanes, for a peneplane is a vast erosion surface developed by streams whose base-level is the sea (Davis, 1909, and Johnson, 1916). A true peneplane, therefore, cannot be carved in an inland desert basin. Pending the general adoption of a special name for the desert erosion surfaces, we shall

FIGURE 137.—The Gobi upland at Ardyn Obo. The field sketch shows: (1) the remarkably smooth erosion plane of the upland, developed on nearly horizontal strata; (2) the extremely short gullies dissecting the scarp; (3) a portion of an extensive lowland, representing the P'ang Kiang stage of dissection.

call them simply erosion planes, and have grouped them, because of their similarity and wide prevalence in the Gobi region, under the generic name "the Gobi erosion plane."

AGENCIES WHICH CARVE THE EROSION PLANE

The only agencies which are capable of carving the erosion planes of the desert are wind and running water, assisted by weathering. It is impossible

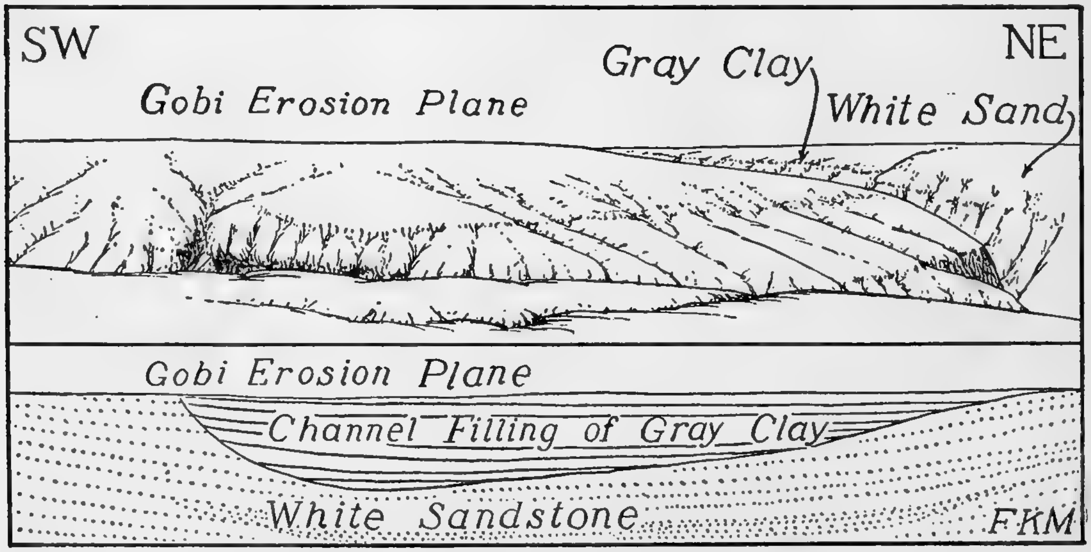


FIGURE 138.—Field sketch of the scarp of eroded Eocene sediments west of Irdin Manha. The smooth erosion plane of the upland bevels the white and gray strata. During Eocene time a small stream channel in the white sands was filled with gray clay. A remnant of the clay is still preserved beneath the thin cover of modern desert gravel.

that waves or glacial ice had any part in the work. The wind acts not only as a carrier for loose waste, but as an actual sculptor. However, the relative importance of wind work as compared with that of running water is difficult to evaluate. There are two general schools of thought on this subject. One group of authorities (Gilbert, 1880; McGee, 1897; Paige, 1912; Bryan, 1922, 1923; Jutson, 1914, Lawson, 1915) holds that running water is a potent, even a dominant, factor in the sculpturing of desert surfaces, while other authorities (Passarge, 1904, 1909; Bornhardt, 1900; Walther, 1912; Davis, 1909, for the later stages of the desert cycle; Hobbs, 1917, 1918; Keyes, 1903, 1908*a*, 1916) attribute the chief rôle to the work of wind. We shall review briefly the results which in Mongolia we attributed to each of these agencies—wind and running water—before discussing the origin of the erosion planes.

Erosion by wind

Despite the stinging sandblast of the big storms, which makes one's skin smart, there is less evidence of actual abrasion by wind than might be expected, and erosion forms are almost exclusively the result of weathering and running water. In the hard-rock regions, we saw monument-like piles of granite, many with overhanging ledges (Plates X, B, page 60, and XI, B, page 61). If they had been carved by sandblast, the undercut bases of the columns, where the attacking sand grains are largest and most numerous, would soon lose their husk of weathered and loosened crystals, and the sandblast would bite into the fresh granite, while higher up, where fewer and smaller grains strike, the rock should stand out as an overhang, its surface deeply weathered but not wind-carved. This interpretation is not sustained by the facts. In every case, the undercut pedestal is so deeply weathered and disintegrated that the specimens we collected with our hammers crumbled to bits. In the same regions, some of the "monuments" have a pyramidal form, and the lower part, most exposed to wind abrasion, is unworn. Thus, both the projecting ledges and the spiring tops are due chiefly to simple weathering processes, acting upon unequally resistant portions of the rock. Where the granite is coarsest, where the crystals are less firmly interlocked, or when the joint cracks are closely spaced, the rock tends to disintegrate more rapidly. No doubt, the wind is one of the destroying agencies, but it plays by no means the chief rôle, since the slow process of disintegration can outstrip it.

In the soft sandstones of the gobis, undercut cliffs were seen which showed evidence of true windblast. The surface is fluted and channeled parallel to the direction of the wind (Plate XIX, page 156), and every little concretion or pebble stands out as a resistant button, followed by a trailing ridge of protected sand on its leeward side. The surfaces parallel to the prevailing direction of the strongest winds are those most effectively carved. Bluffs that stand transversely to the prevailing winds are commonly banked by drifting sand, and so are protected from erosion.

The wind undoubtedly plays an important part in excavating the undrained hollows which form one of the most conspicuous features of the desert landscape; but as their development involves a number of complexly interacting agencies, it seems best to treat the origin of desert hollows as a special subject (page 336).

The destructive work of wind is very easily hindered. A blanket of drifting sand protects level surfaces and even steep declivities from active erosion. Where level surfaces are exposed to the strongest blasts, the wind carries away the finer particles of weathered rock, and the heavier and firmer fragments remain as a "desert armor" which reduces wind-erosion to almost infinite slowness. If there is enough moisture to support either a lake or an effective mat of vegetation, wind scour is checked. The wind is, therefore, a weak agent of erosion, abrading rocks no faster than they break down under ordinary atmospheric weathering. But as a transporting agency, moving the finer and lighter materials about and depositing them, it plays a vitally important part, and is the only power that can carry sediment out of a wholly enclosed basin (page 336).

In taking up the work of running water in a desert region, the questions which first arise for consideration are: How much water does the desert receive, and how is it distributed?

Rainfall

Rain, in this northernmost of the world's desert basins, is most frequent and heaviest along the Arctic and Pacific divides, and lightest over the open lowlands. The bordering ranges, receiving their supply from the great stretches of Siberia on the one hand, and the Pacific Ocean on the other, have a richer water supply than even such high interior mountains as the Altai. Lacking all figures, and basing our estimate upon the general aspect of the vegetation, we hazard a guess that the rainfall varies from about thirty inches along the Arctic divide and about twenty inches on the Pacific divide, to eight or ten inches in the arid centers.

The Mongols tell us that the midsummer rains, occurring in late July and August, are the heaviest of the year. As a rule, the rain falls in light showers, occasionally in long wetting drizzles, and still more rarely in short squalls that beat through the tents and cover the flat desert surface with a thin sheet of water. We have seen as much as one third of an inch fall in a single storm; but we never saw such violent "cloudbursts" as Walther describes for the tropical deserts: storms which, at long intervals, break over quite restricted areas, carving and removing large amounts of coarse material in a very short time. For example, at Wadi-Abu Shuasha, "blocks of the pavement ran for many meters through the streets of Helwan, gliding on the small pebbles as if on rollers" (1912, page 34). The evanescent streams in the Gobi must be vigorous when they run at all, judging from the great ripple-marks and scour channels and from the cobbles and coarse gravel which they move; but the moraine-like masses of washed-out débris, described by Walther, are absent. It seems probable that in tropical deserts, especially those near the sea, sudden and extremely violent storms are to be expected, but that rains are lighter in the cooler deserts of higher latitudes, even though there be a greater annual rainfall. There is a light winter snowfall, but not enough to prevent the herds from grazing on the dried remnants of the summer vegetation. This condition is so nearly uniform that hardly any of the Mongols store winter food for their herds.

Drainage

In a well-watered region, large rivers can maintain their courses during deformation of the country, provided the rate of deformation is slower than the rate at which the river can cut down its bed. In a desert, where few streams are constant and fewer streams are large, the rivers, as a rule, must adjust themselves to any change of slope that may arise through earth movements (Davis, 1909, page 299). Nearly all the streams of Mongolia are consequent upon the slopes of the warped and faulted basins and ranges. They therefore flow inward, radially, toward the centers of the depressions. This centripetal drainage pattern is repeated on an ever diminishing scale from the great basin of Mongolia and its subdivisions, the talas, down to the small erosion hollows excavated in the desert surface, each of which has its own little system of contributory gullies. The larger rivers are not connected to form an integrated drainage system; instead, each terminates in a lake. The smaller drainage systems are still less integrated, most of the streams dying out before they reach the center of the desert hollows. There are two general types of stream in the Gobi region: (a) Streams rising beyond the desert border in humid areas, and flowing thence into or through the Gobi Desert; (b) streams that originate in and belong wholly to the desert. The first type may be called immigrant streams, and the other, native streams.

Immigrant Streams.—Most of the larger rivers of the Gobi are immigrants: either the traversing rivers that pass through the desert, or the terminating rivers that die in the desert. Only two reach the ocean, the Hwang Ho and the Kerulen. The Hwang Ho, in passing from Lanchowfu to its junction with the Wei Ho, makes a great bend around the Ordos Desert, and virtually into the Gobi. On the northern border, the Kerulen rises in the well-watered Kentai Ola and runs through the desert to the Dalai Nor which drains into the Amur River. Most of the larger streams of the Gobi rise in the rainy mountains, and terminate in the lakes of the desert basins. They have many tributaries near their headwaters, but few or none in the arid lowlands, where they flow through swampy valleys, walled in by low, steep bluffs. If they receive water in the desert, it must come from local rains, springs, and seepages. As they run, they lose water through evaporation, and locally through seepage, until the loss just balances the supply. Here they end, whether the terminal basin is reached or not. Thus, the Ongin River ceases to flow as a surface stream long before it reaches its terminal lake, Ulan Nor; and the Tatsin River for many years has not as a living stream touched Tsagan Nor, which is its geographical terminus (Fig. 98, page 194). While the immigrant rivers from the Arctic divide run to within twenty miles of the Altai front, most of the native streams rising in the Altai die out at its very foot.

Native Streams.—In contrast to the long streams that head in the bordering mountains, the desert is carved by many short river systems which depend upon local rain, melting snows, and ground-water issuing as seepages and springs. Many of the mountain-fed streams disappear into the gravels of the alluvial fans. Where mountains immediately adjoin gobis which are filled with porous sediments, the sinking streams and melting snows of the mountains feed the sponge of sediments, especially when the strata in the basin are upturned along the mountain front. The ground-water table in the mountains is higher than in the gobis, so that water also passes underground through crevices from the mountains to the sediments. The mass of ground-water moves slowly downward toward the depressed centers of the talas and gobis. As it moves, some of it is drawn upward by capillarity and evaporates from the sun-baked surface. Whenever the water-table meets the surface of the earth, seepages and springs break forth, which may feed existing rivers, or may start new drainage systems.

Rainwash will, at favorable places, incise the desert surface and start a new set of stream heads, which may, or may not, receive support from ground-water. Running together, great numbers of such rills form a river which cuts a valley in the erosion plane of the desert. But the thirsty air takes its tribute of vapor, and water is lost by sinking into the ground, until the new river finds its load too great to carry, and deposits part of it. The stream now ceases to cut a valley and spreads over the surface, laying out a broad thin apron of loose sediments which is attacked by the wind as soon as it is dry.

Farther down the slope of the erosion plane, the rain-wash and ground-water may again start a new system of streams—a system which converges into a main trunk and dies out, like the first, in a flat outwash apron. Streams such as these may succeed one another until the lowest one falls into a lake basin where a final balance is struck between water supply and evaporation. This type of stream does important work in carving desert hollows, and is discussed further in that connection on page 338. One of the best examples of this type of stream is the Hsanda Gol, of which we made a reconnaissance map (Plates XXVII, XXVIII, and XXIX). It collects innumerable tributaries about its head, which lies between Uskuk Mountain on the west and the three big buttes on the east. It carves a trench 150 feet deep and locally more than half a mile wide. After running southward twenty miles and descending more than 1,500 feet, it emerges into a broad desert hollow. The walls on either side of the valley turn east and west away from the river, which there distributes a broad, flat, alluvial fan over several square miles of country, and comes to an end. The amount of sediment it has actually laid out is astonishingly small when compared with the immense excavation of its valley and the valleys of its tributaries. Going southward, within three miles after leaving the valley of Hsanda Gol, the river deposits thin out and come to an end, and we find ourselves again traveling upon bedrock. We suppose that, when the river is in flood, it spreads out so thin a sheet of fine waste that much of it can be carried away by the wind after the river has withered.

Erosive work of running water

One of the many surprising paradoxes of the Gobi Desert is that the most important eroded surfaces are not, as one might expect, the work of wind, but the result of erosion by running water.

In the well-watered mountains, such as the Khangai, the rivers merit no special discussion, as they behave like mountain streams in any other part of the world. But in proportion as the mountains become drier, the valleys become more closely spaced—another of the paradoxes of the desert; for with a thinner web of roots to hold both soil and water, the rainwash cuts shallow, closely spaced gullies instead of the fewer and larger valleys of the Khangai (compare figure 106, page 224, with figure 149, page 344). When rain falls or snow melts in the dry mountains, the water finds a steep slope to give it power, and plenty of loose material to carry; and in its short-lived vigor, it rushes blocks, bowlders, and sand down stream. The pebbles and sand are more easily moved than the larger blocks, and eventually the floors of the lower valleys, where the gradient is less steep, become armored with bowlders, while the finer materials are carried down into the alluvial fans. Not all the streams acquire their armor by the simple method of transporting it; some inherit bowlders which descend from terraces through which the stream has cut, and some receive them from landslides or from cataract tributaries. Weathering, soil-creep, rainwash, and tributary streams continue to wear the walls of the valley, while the main river does at least a little lateral cutting. The valley thus widens slowly in its lower reaches, without much deepening, provided the supply of water remains nearly constant; but in wet climatic cycles, the increase in rainfall revives the river, which, leaving a remnant of the bowlder-strewn floor as a terrace, sinks a new narrow trench in the bedrock, at the same time dissecting its own alluvial fan along the mountain front.

THE PIEDMONT SLOPE

The gently sloping surface that descends from the mountain is an erosion plane, diversified by alluvial fans draped along the front of the range (Fig. 139). The slope is concave, steepening toward the mountain base, until it attains a gradient of five to seven and even ten degrees, which exceeds by three to four degrees the maximum inclination of the alluvial fans.

In August, 1922, we were camped at the foot of Artsa Bogdo, on the rock shelf which stands forty feet above the streams issuing from the mountain,

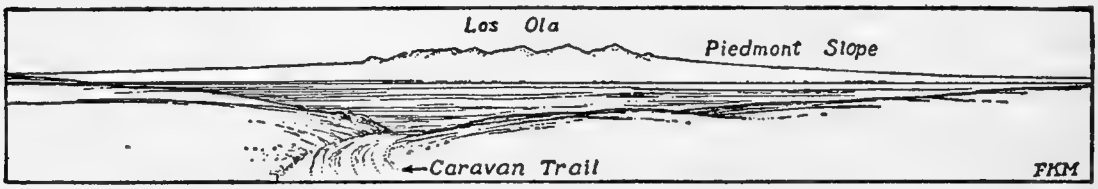


FIGURE 139.—The piedmont slopes of Los Ola, from a photograph. The piedmont slope is a composite of eroded rock bench and alluvial fans.

and has a slope of eight degrees. During a rainstorm which lasted for about two hours, the water swept in a sheet under our tents, though after the heaviest squall it settled into shallow runways. The rock surface of the erosion plane is marked by an infinite network of shallow rill courses, and is thinly and unevenly strewn with small chips of native rock, which no doubt are carried by vigorous little streams such as we saw form and fade during the storm. They are the tools with which the running water abrades the bedrock, which is so deeply weathered and disintegrated that we found it impossible to secure fresh samples, except in the walls of the deeper gullies; for mechanical and chemical weathering are especially active along the mountain foot, where rocks are alternately saturated and dried at frequent intervals, and where the surface run-off and the underground escape of water are slower than in the steep mountains. The wind does not contribute to the carving of the erosion surface, except in a very minor degree; the chief rôle must be ascribed to the myriad short-lived streamlets acting upon the weathered rock of the piedmont. These transient rills run together into little drainage systems, which are not wholly integrated, but may either fall into some larger channel, or may die out leaving a thin, flat cover of angular fragments over the slope.

The larger channels of the mountain streams have cut shallow but steep-sided trenches across the slanting piedmont surface, whether this be composed of alluvial fans or bedrock or both. Their intrenchment is due at least partly to a revival of the streams during the latest epoch of wet climatic conditions. The valleys flatten out at varying distances from the mountain front, and the streams vanish into the general waste-covered slope. Still farther down, new systems of valleys appear, where ground-water coöperates with rainwash along the thinning edge of the alluvial fans. The piedmont bench is thus a complex surface, or rather several surfaces of diverse age and origin, including alluvial fans formed by deposition, rock benches cut by streams, and the ever widening valley bottoms of the streams which dissect the fans and the benches.

In order that a nearly smooth surface may be carved across rocks of diverse quality and structure, there must be some means of limiting the tendency to cut downward; otherwise, all streams would continually deepen their valleys, and those which rest upon soft rocks would dig in faster than those which flow over hard rocks. The influences which tend to limit the depth to which the piedmont streams may cut are the relations between the supply of water, the load of sediment, and the gradient of the river-bed. When the climate is dry, the supply of available débris is always large in comparison with the running water, so that the floor of the lower part of the valley, near the mountain front, becomes thinly armored with waste which the stream can just move when in full flood. The rate of downward cutting is now slowed to a minimum, and will remain so as long as the rainfall, and especially the number of effective storms per year, stays fairly constant, maintaining the equilibrium between current and load; a river in this balanced condition is said to be "graded," or "at grade." (Davis, 1909, page 390.) With an arid climate, a stream will become graded with slopes far steeper than in a rainy climate. The small rills on the divides between the main streams, issuing from the ravines in the mountain, are working with a steeper gradient on bare, much weathered rock, and carry a light load. They cannot wear down quite to the level of the graded master streams, which serve as a controlling base-level, but they can keep the divides worn down to a slope not many degrees steeper than that of the graded streams.

The whole piedmont slope becomes lowered very gradually as the graded streams cut downward, and becomes lengthened very slowly as the mountain front is cut away. Here and there, masses of upstanding rock are left towering above the nearly smooth surface. Just why they should be spared in the general planation, it is often difficult to see. Some are preserved because they are made of or are capped by hard rock, such as lava or conglomerate; but others, such as folded limestones or uptilted porphyries, are apparently of the same stuff as the beveled floor surrounding them. Where there is a piedmont slope, it merges into the smooth erosion surface which bevels the broad gobi basins, and which we shall call the Gobi erosion plane. This does not mean that a single erosion plane extends continuously throughout the minor basins of Mongolia, for a very similar surface is developed in separated basins and at different elevations above sea level.

THE GOBI EROSION PLANE

The popular concept of the typical desert basin is a sediment-filled hollow, in which material washed down from the surrounding mountains has been collecting continuously from the time of the formation of the hollow to the present. If this were the case, the topmost sediments would be recent, and the surface of the basin would be, in the main, an original surface of deposition, sloping at the angles of repose characteristic of alluvial fans, flood plains, deltas, and lake deposits. On the contrary, in Mongolia, most of the sediments are Cretaceous and Tertiary, and the surface proves to be one of erosion rather than of deposition. East of the southern margin of Uskuk Mountain, the surface bevels steeply upturned sediments (Fig. 111, page 245), while along the general line of the Hsanda Gol, the nearly flat upland rests successively upon beds ranging from Lower Cretaceous to Miocene age; near Shara Murun, the same smooth and almost flat upland bevels Oligocene and Eocene formations; between Irdin Manha and the Houldjin bluff, a similar level upland passes from Eocene to Oligocene beds (Fig. 102, page 201). Even upon horizontal strata, where the evidence is less openly readable, the fact that the surface rests successively upon formations of diverse age can only mean that it bevels across their structure. It is impossible that the original surface of a Cretaceous deposit could be preserved so perfectly that it would be now in the same stage of dissection as the original surface of an Eocene or Oligocene deposit, nor could they both be in the same stage of dissection as an original surface of Oligocene or Miocene age. The striking similarity in the smooth uplands, developed upon rocks of diverse age, resistance, and structure, throughout a vast area, must mean that these surfaces are erosional, are due to the same agencies, and are everywhere of nearly the same age.

Superposed on the erosion surface are Pleistocene fans and gravels, and post-Pleistocene sands forming sheets and dunes. Here and there the upland is carved by streams, and in many places it is indented by large and small hollows.

There are thus four elements in the surface of the desert basins—the first three belonging to the erosion plane: (1) Slopes and irregularities of the original erosion surface; (2) deformation of the surface by tilting or warping; (3) erosion of the surface; (4) deposition of material upon the surface.

In a region where warping has taken place at intervals throughout the entire history of basin-making, it may be very difficult to tell an original slope from a deformation.

Original slopes of the erosion plane

The plane is remarkably smooth; in some places the expanse is so broad that the horizon appears as unbroken and as level as the sea-circle around a ship. The gradients of most of the Gobi uplands cannot be stated accurately, as the Expedition traversed most of them along a single line. Some of our records of extraordinary flatness, for example across the Irdin Manha basin (page 57), are probably due to our having traveled almost exactly at a right angle to the direction of the slope.

The Gobi upland, east of the Ongin Gol valley, between Khurul Obo and the Sair Usu trail, is one of the smoothest stretches we have seen (Figs. 69 and 70, page 160). It rises northward, at about ten feet per mile—a gradient that in a wet climate would give ample energy to running water; a gradient many times that of the Mississippi below St. Louis. It seems possible that, in a climatic cycle somewhat more humid than the present, sheet flood erosion and the wash of a net of small local streams might do much toward the leveling of an erosion surface upon soft Cretaceous or Tertiary sediments.

Deformation of the Gobi surface

Great caution is required in judging whether a given surface has been tilted by earth movement or carved at a slant. In general, slopes which are notably steeper than those of the graded streams are judged to have been tilted. Arched or domed surfaces are undoubtedly deformed.

As one of the best examples of deformation, we may cite the domed surface east of the Uskuk block (Fig. 108, page 239), an account of which is given in Chapter XIII. Farther south, near the Altai front, there is evidence of faulting since the broad upland valleys were carved (Plate XXX, in pocket). In a later publication, we shall offer a more complete discussion of the piedmont of Baga Bogdo.

In some cases, slight deformation of the Gobi surface seems to have determined the courses of rivers whose valleys now dissect the erosion plane. For example, the course of the Hsanda Gol is down the shallow notch between the Uskuk block and the Shiliuta dome just east of Uskuk.

Deposits on the Gobi upland

Two characteristic deposits overlie the Gobi upland. Gravel covers by far the larger part of the upland surface. Its only rival is wind-blown sand, which, though far less extensive, covers broad areas. The gravels on the erosion plane are of two general kinds: those which come from the underlying materials, and those which are carried from some other place.

As the surface of the desert becomes lowered by weathering and removal of the finer grains, the most durable materials remain on the surface, gradually accumulating until they form a cover (Fig. 140). We have observed the following common types: (1) Dense dike-rocks and veins of quartz, epidote

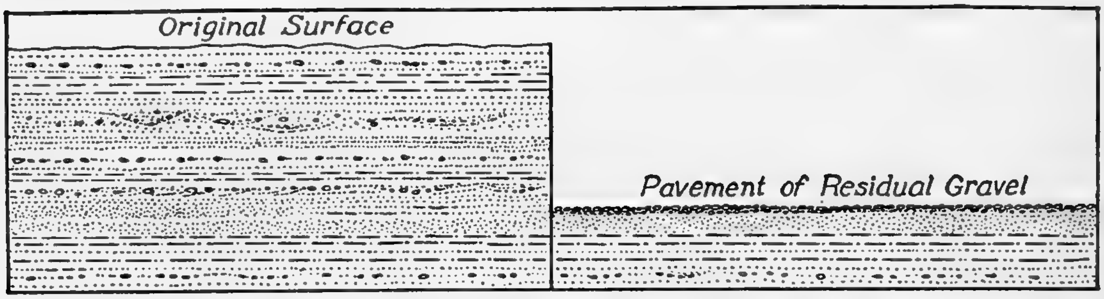


FIGURE 140.—Diagram illustrating the origin of residuary gravels. The left half of the figure shows a bed of friable sediments containing pebbles. The right half shows the fine material blown away, concentrating the pebbles in a surface gravel.

and colloidal silica, weathering out of granites; (2) quartz veins, weathering out of schists, phyllites, and graywackes; (3) veins and masses of jasper or chalcedony, weathering out of ash or sediment which they have replaced; (4) beds of silicified ash, breaking down into hard strong fragments; (5) amygdules of silica, weathering out of basalts; (6) flints and partly silicified concretions, weathering out of limestones; (7) pebbles, released from conglomerates through the dissolving of the interstitial cement; (8) concretions of sandstone and lime. Neither of these types of concretions lasts long.

Each type of pebble is especially abundant near its source, but all pebbles tend to be distributed over the surrounding country wherever a downward slope favors the wash of shallow temporary streams. The gravel cover may be almost wholly a residue of the decaying rock beneath, or it may be wholly washed in by streams, or it may represent a mixture of residual and transported pebbles.

Where the surface truncates the lava flows of Cretaceous or Tertiary age, the gravels consist largely of chalcedony and agate amygdules, weathered out of the basalt. The pebbles have traveled somewhat, as foreign pebbles are mingled with the residuary agates, while the latter are found far outside of the lava areas. At Oshih, for example, the gravel overlying the basalt consists almost wholly of chalcedony amygdules weathered out of the lava, while the exposed sediments are covered by pebbles which could have been concentrated from the pebbly strata (Fig. 140). At Ardyn Obo and at Irdin Manha the upland gravels are largely residual, as the pebbles match those of the underlying beds. Even in these places there has been some transportation, for locally we find the gravel concentrates in shallow channels, where the contact between the gravel and the underlying sediment is sharp.

On the upland at Djadokhta, the dark gravels are one to five feet thick, and are notably cross-bedded. They contrast sharply with the fine uniform red sands of the Djadokhta formation. The latter does not contain such pebbles, and therefore the prolonged erosion of the sand could not have yielded the gravels as a concentrated residue. The fact that the pebbles were not derived from the underlying sediment would not, of course, preclude the possibility that some younger formation, such as the Gashato, which once rested upon the Djadokhta, might have yielded the pebbles, and might have been wholly destroyed.

At Shara Murun, the erosion plane descends westward across Oligocene beds of two diverse aspects, and one Eocene formation. It is mantled with gravel, which varies in thickness from three to twelve feet, and is everywhere coarsely cross-bedded. The gravel is clearly later than Oligocene, and rests upon the smoothly eroded surface of the early Tertiary beds. It evidently was washed into place by streams—very probably the same streams that carved the surface upon which it rests. In general, the residuary gravels are thinner than the beds of transported pebbles. Very commonly, a cement of limy matter deposited by evaporating ground-water binds the upland gravel loosely together, or in rare instances, cements it into a massive conglomerate.

Where the Gobi upland is trenched by stream valleys or by undrained hollows, the gravel cover is redistributed over the slopes and upon the new lowland. In some cases, it covers the floor as effectively as it formerly covered the upland. In others, it may be commingled with, or buried by finer sediments washed from the surrounding scarps. Even in the latter case, the selective removal of finer dust and sand by the wind tends to bring the pebbles to light again, and to reform the gravel armor.

The only other cover commonly seen upon the upland is sand, which is blown out of the valleys and hollows, and is spread over the upland in the form of a thin sheet, or of hummocks, held by grass and bushes; more rarely the sand may be heaped up as veritable dunes. Wind-blown deposits are discussed further on page 350.

Redissection of the Gobi erosion plane

At the present time the Gobi erosion plane is not being formed; on the contrary, it is being eroded and destroyed—in part by streams and in part by the work of the wind. Undoubtedly there has been a change from conditions which favored the making of such a plane to conditions favoring its destruction.

We have considered the probability that, in carving the smooth erosion plane of the Gobi, a considerable part was played by graded streams. An increase in water or a deformation which resulted in steepening the slope would cause all rivers to incise their channels and sink new and narrow trenches into the underlying rocks. A lessening of either water or slope would cause the streams to die at shorter distances from their sources, dropping their load, and so building up the surface until it attained a slant that again established a graded condition of the rivers. In the case of a diminution in the activity of running water, the wind would accomplish more efficient erosion, partly because the protecting tissue of plants becomes thinner, and partly because the power of the wind has remained constant while that of its great rival, water, has diminished. Wherever the ground is especially favorable to attack by wind, undrained hollows will be excavated.

Summary of the Gobi erosion plane

The Gobi erosion plane thus appears as a series of wide stretches of wonderfully smooth country, sloping very gently except where it has been recently deformed. It bevels horizontal and tilted strata with almost equal smoothness, and in places laps over the complex rocks of the ancient floor. It is of comparatively recent origin, as it overlies all the sedimentary formations, including the latest Pliocene or earliest Pleistocene, yet it is being destroyed, not formed, in the present epoch—a fact which indicates that it was formed under somewhat different climatic conditions from those of the present time. Its destruction is being brought about partly by the work of streams, especially near the rainy mountains, and partly by the excavation of undrained hollows, especially in the arid central basins. We are not yet sure what may be the details of the origin of such erosion planes; more light is to be expected from the study of regions where these planes are now being formed.

DESERT HOLLOWS

On the night of April 23, 1922, we camped near the telegraph station of P'ang Kiang, on the floor of the first large, clearly defined desert hollow which we had crossed in our journey (Fig. 141). Subsequently we were to see hundreds of such hollows, some larger and many smaller than the one at P'ang Kiang. They are all formed in the same way, and are of later origin than the Gobi erosion plane in which they are cut. We gave the name "P'ang Kiang" to the stage of erosion which they represent.

The desert hollows could not possibly be excavated without the work of wind; no other agency could lift material out of an enclosed lowland. Almost every day while we were camped in such a hollow, we saw the "whirling pillars" of dust racing across its dry floor. During violent windstorms the air was dark with flying dust and sand and the sun was dim and red. Dust veils hung in the air for several days after the biggest windstorms. Much of the stirred-up sand and dust settles upon the surrounding country, but no

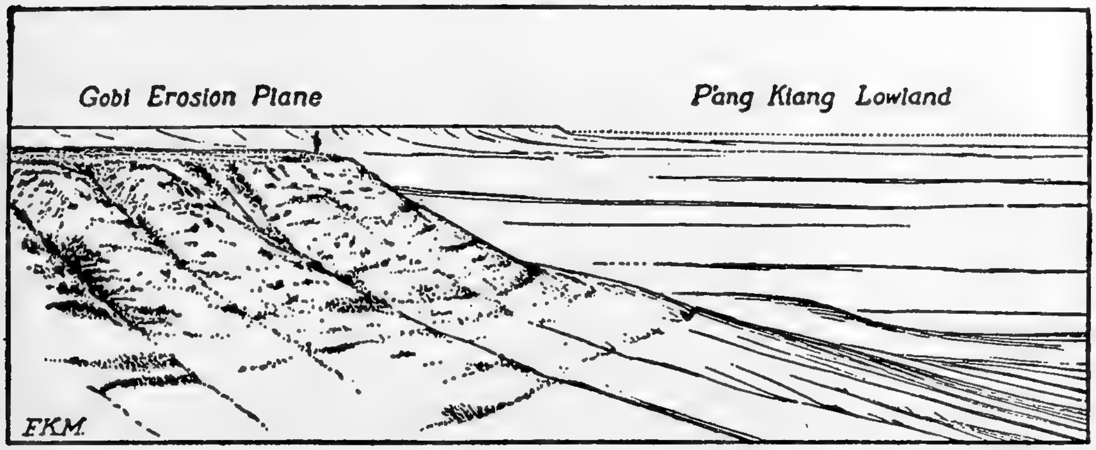


FIGURE 141.—The western scarp of the lowland at P'ang Kiang.

doubt some of the finer material is exported to great distances, even beyond the rim of the Gobi.

We have tried to determine the conditions which favor the commencement of excavation, and may list them briefly as follows:

(1) The gravel cover of the Gobi upland is thin or absent;

(2) The underlying sediments are fine-grained, such as sand or sandy clay, and are not well cemented;

(3) The ground-water level does not lie near the surface;

(4) Vegetation is sparse or has been killed by drought;

(5) A small pond dries, leaving enough salt to prevent vegetation from covering the exposed bed, but this condition rarely obtains on the Gobi upland, though it is not uncommon on the floors of the hollows;

(6) A stream has cut a shallow trench in the upland, piercing the gravel cover and exposing the finer sediments, which during the dry seasons or epochs lie bare to the attack of the wind.

Any of these conditions, or any combination of them, may determine the place where the wind can begin to excavate a hollow. How deep the wind can dig is controlled, in turn, by a number of limiting factors, among which are the following:

(1) The floor of the hollow may come near enough to the level of groundwater to encourage a vigorous growth of plants, which checks further erosion.

(2) A layer of gravel may be developed, partly by blowing away the finer particles from the beds of sand and clay, and concentrating the pebbles which

they contain, and partly by washing down gravel from the upland surface. Where the lowland gravel is thick enough, it effectively checks the ravages of the wind.

(3) The floor may be cut down until it rests upon a layer so well cemented, or composed of conglomerate so coarse, that the rate of wind-erosion is slowed to a minimum.

(4) Rainy seasons or a rainy epoch may raise the ground-water level sufficiently to support a shallow lake in the hollow.

(5) Salts may be brought to the dry surface by capillarity, and may cement the ground so firmly, that it is virtually a rock, on which the wind works very slowly. The drying lakes may leave crusts of salt, which protect the surface, and the salt absorbs enough moisture from the air, or from the ground, to enable it to recrystallize and recement itself when broken by the tread of animals. Nevertheless, when the lake plain is thoroughly dried, salt is exported along with dust.

Any of these conditions, or any combination of them, may tend to limit the depth of the hollow, which, throughout Mongolia, is shallow—rarely more than 400 feet.

The sides of the hollow are dissected by rainwash and by rills from the upland. During epochs of active erosion, the sloping bluffs are fretted into

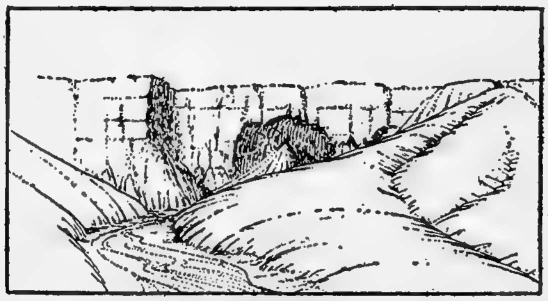


FIGURE 142.—The abrupt heading of the short gullies that dissect the scarp at Ardyn Obo.

typical badlands, and the loose sediment is washed down to the floor of the hollow. As soon as the thin flat apron of sediment is dry, it is exposed to the tireless winds, which carry much of it out of the hollow. The retreat of the bluffs and the lateral enlargement of the hollow is thus mainly the work of running water. Because most of the streams that run into the hollow are temporary rills that flow only while the rain falls, vigorous cutting will not be done, except on the steep slopes. Gullies are rarely seen on the floor of the hollow, and still more rarely on the upland. The gullies along the bluffs are very short, heading a little way behind the edge of the scarp and dying out a short distance beyond its foot. (Figs. 137, 138, 141 and 142.) There is thus a narrow zone of active stream-dissection along the scarp—a zone which retreats with the scarp as the latter is cut back.

Where there is enough rain to encourage a thick growth of herbs and small bushes, yet not enough to support a drainage system of permanent streams,

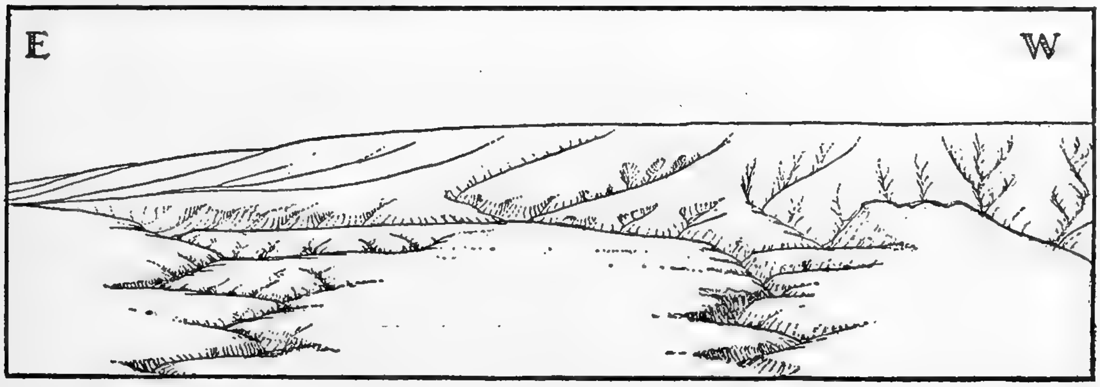


FIGURE 143.—Re-dissection of a smooth scarp at Shara Murun. The drawing illustrates the transition from the smooth slopes, at the left, to the redissected badland condition, with reversed scarps, seen in the foreground.

the mat of vegetation may check the dissection of the scarp for a time. The profile of the bluff weathers into smooth, gently rounded slopes (Fig. 143). Locally, gravel from the upland washes down and mantles the lower slopes,

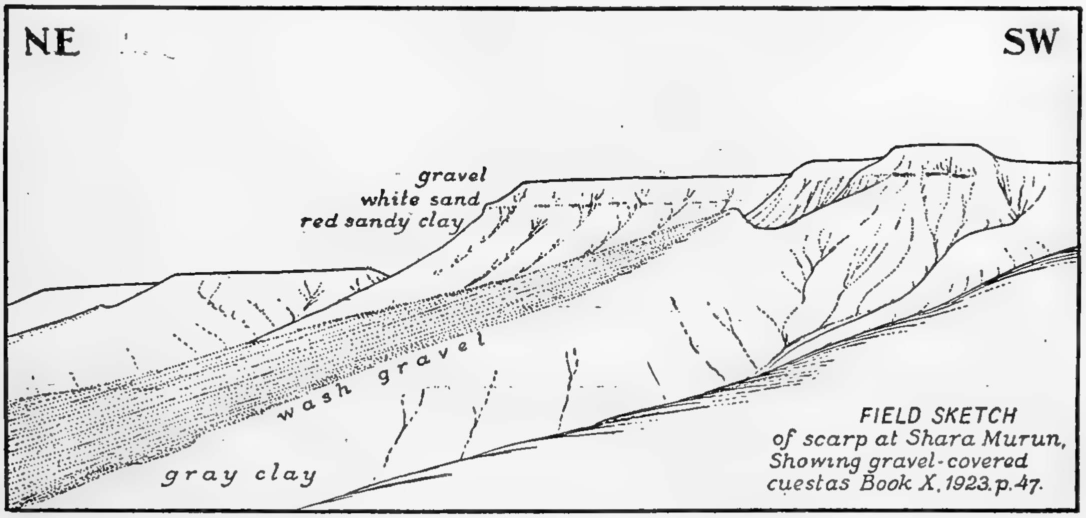


FIGURE 144.—Early stage in the development of a reversed scarp. The smooth back slope of the reversed scarp in the foreground, preserves a remnant of the former condition in which the whole scarp had this form.

though it cannot cling to the steeper part of the declivity. It forms a protecting cover even in the absence of a well-rooted mat of plants.

With the approach of a dry epoch, the plant cover dies on the exposed slopes, just where the steepness gives the rainwash its maximum speed and erosive power. Short gullies are carved (Figs. 144, 145, and 146), transforming the green, rounded slope into a torn badland of exposed strata. The cliff is cut back, enlarging the hollow, while the rills die out on the floor, spreading

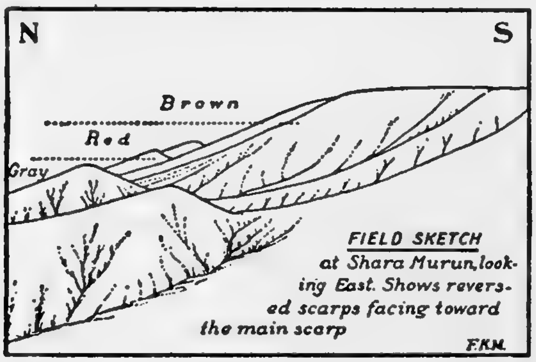


FIGURE 145.—Late stage in the development of a reversed scarp.

their burden of sands and clay. The significance of the periodic renewals of dissection is considered further in Chapter XXI.

Undrained hollows were found in granite regions also. They are most common in coarse-grained granites, and seem to coincide, in part at least,

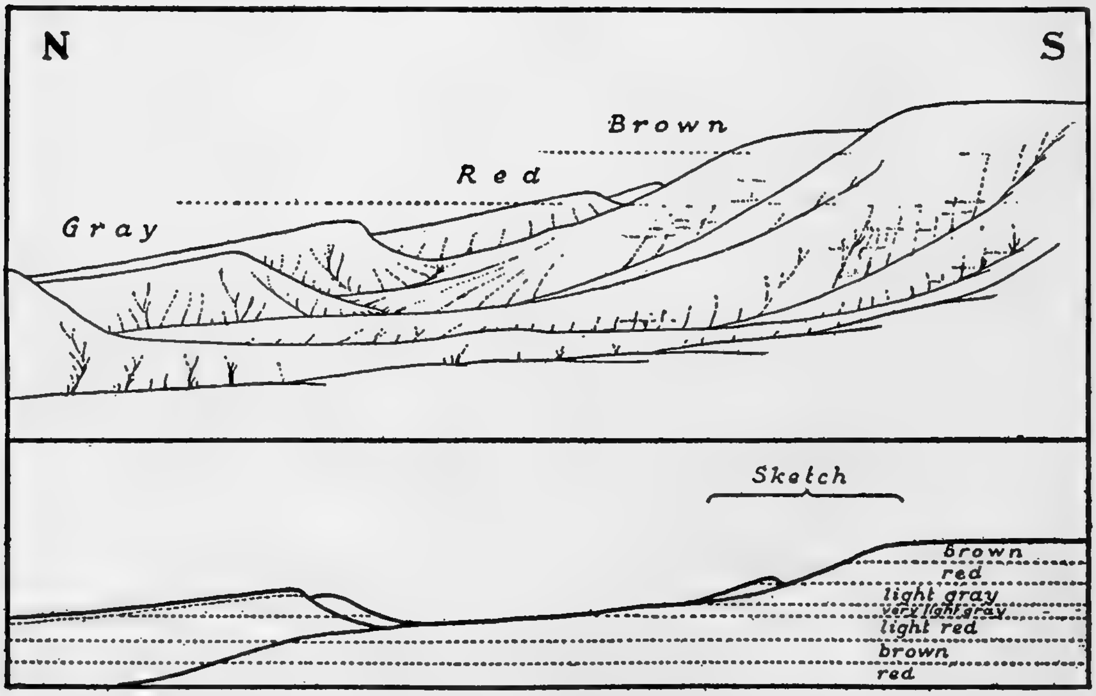


FIGURE 146.—Reversed scarps at Shara Murun. The scarps resemble cuestas but are composed of horizontal strata. The cross-section, below the sketch, extends a half mile farther out into the lowland than the sketch above, and shows an additional older reversed scarp. The area of the section covered by the sketch is included within the limits of the bracket.

with the pattern of stream courses (Fig. 46, page 117). There is surprisingly little waste in the hollows—only a thin cover of arkosic sand and, locally, a rubble of disintegrating granite blocks. (See Plate XVII, A, page 143.) The coarse granite tends to break up under the action of frost and changes of temperature. It weathers chemically also, for the rock bears rusty stains, and the feldspars are somewhat kaolinized. As the rock disintegrates into grains which the wind can carry, these grains are removed, and the hollow deepens until it approaches the depth at which ground-water lies. The sides of the growing hollow are carved by short evanescent streams, just as in the sediment-basins. During dry seasons or cycles, the wind will continue to blow away the finer dust and to deepen the excavation. Should the ground water level rise during a season or cycle of heavier rainfall, a pond will form in the bottom of the hollow, and the exportation of material will be checked, although rills which course down the sides of the bowl may continue to enlarge it laterally. (See also Chapter XXI.)

THE OLDER PENEPLANES

The oldrock surfaces of Mongolia bear clear record of several periods of planation older than the Gobi upland. We observed at least two such planation products, whose relations to one another are not quite clear. Doubtless there are still others, less conspicuous, whose traces may serve to confuse the problem (Fig. 110, page 242). Lacking reliable maps or surveys, and traveling as we did along a single route, it was impossible to study adequately these erosion surfaces, but, at least, the major features of the problem deserve a brief statement.

The pre-Cretaceous peneplane

The oldest basin sediments, of Lower Cretaceous Age, rest upon a nearly smooth erosion surface, which truncates the edges of the complex rocks of the floor. In some localities it can be shown that the peneplane exposed at the mountain tops, was once buried and is now being laid bare by the stripping of the sediments which formerly covered it. This is the case at Uskuk Mountain (Fig. 110, page 242), where early Tertiary sediments, and possibly Cretaceous beds as well, once covered what is now the top of the mountain block.

It is a possible interpretation, therefore, that the Mongolian peneplane, which bevels the mountain tops, is the surface upon which the earliest basin sediments were laid down, and this was, indeed, the theory with which we at first worked in the field. But as we obtained increasing evidence of the widely different periods of basin-warping, it was judged that the entire history was more complex than it seemed at first. The following considerations are some of the elements of the problem.

Buried unconformities and disconformities are numerous and imply long gaps in the sedimentary record. Thus, in the Altai region, at least two of the gaps in the sedimentary record represent planations—one at the base of the Cretaceous, and the other at the base of the Tertiary, when the faulted and tilted Mesozoic rocks were reduced to base-level (see Chapter XIII).

The Mongolian peneplane

A clearly defined ancient erosion surface bevels all the mountainous areas of Mongolia. Remnants of an older unreduced upland rise above it as monad-

FIGURE 147.—The Mongolian upland in the Chakhar Mountains. The maturely dissected Mongolian peneplane bevels hills of granite and schist in southern Mongolia. The distant landscape appears monotonously smooth in every direction.

nocks, and the valleys carved out below the peneplane represent a dissection so mature that by far the major part of the old flat surface has been destroyed. Provisionally, this upland surface has been called the Mongolian peneplane because of its widespread distribution in Mongolia.

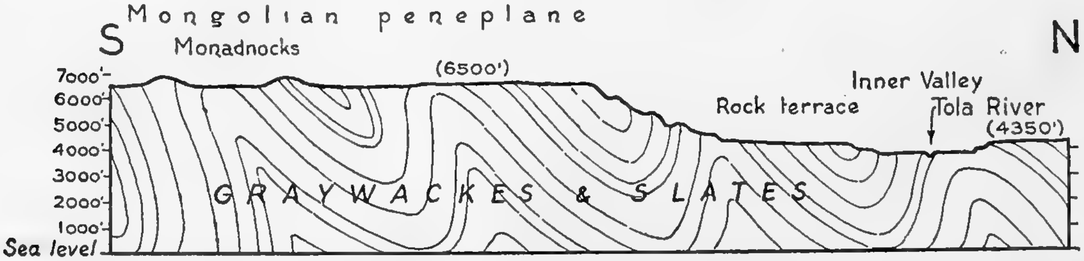


FIGURE 148.—The Tola River terraces. The figure shows: (1) the Mongolian peneplane with surviving monadnocks, (2) the broad rock terrace of the Tola River, (3) the modern river trench within which the Tola River meanders on an aggraded floor.

The peneplane was first observed in the granite mountains of southern Mongolia, at an altitude of 5,300 feet (Fig. 147). But as we climbed toward the Arctic divide, south of Urga, an old surface was again seen at about 6,000 feet, beveling the schists and the younger graywackes. At the Tola River, near Urga, the following topographic elements were observed. (1) Monadnocks rising above the Mongolian peneplane; (2) the peneplane; (3) a broad rock shelf, or terrace, within the valleys of the Tola and its tributaries; (4) an inner valley, sunk gorge-like below the rock terrace, yet having a mature floor upon which the river meanders. These relations are expressed in figure 148.

The Khangai peneplane

When we climbed into the Khangai Mountains north of the great lamasery of Sain Noin Khan, we saw a smooth upland, dissected by streams and, in the highest parts, by former glaciers. Above the peneplane rise notable monadnocks. The physiographic unconformity between the valleys and the ancient upland surface is clearly seen (Fig. 149). We were not wholly sure of the identity of the upland with the Mongolian peneplane, and so called it provisionally the Khangai peneplane. It stands at about 10,000 feet where we observed it, and so should be older than the Mongolian peneplane, unless the two erosion surfaces can be shown to be identical. There is a shoulder of rock terrace bordering the valleys.

Descending from the Khangai Mountains and going southward, we followed the peneplane, as carefully as possible, to test its relations with the Mongolian peneplane. The valleys broaden southward, and the rock benches within the valleys tend to coalesce so that remnant hills or outliers of the Khangai Mountains are cut off from the long spurs and lie isolated, surrounded by the erosion lowland. As we look southward, from such border fringes of the Khangai hills, it seems that a new, lower beveling continues southward over the tops of the ranges there. Lacking adequate maps or surveys, we found it very difficult to be wholly sure of such a correlation; but if our observation was not at fault, it would support the inference that there are two peneplane surfaces beveling the hard-rock structures of Mongolia: an older Khangai peneplane, and a younger and lower Mongolian peneplane (Fig. 150, A).

Relations of the Khangai and Mongolian peneplanes

If we assume that the Khangai peneplane is the older (Fig. 150, A), the significant steps in the physiographic history may be summarized as follows:

(1) There was a complex mountainous oldland; (2) the oldland was reduced to a base-level or peneplane, above which stood low residual elevations or monadnocks; this is the Khangai peneplane; (3) the region was uplifted; (4) it was then subjected to erosion so prolonged that the Khangai peneplane was wholly destroyed over a broad area, and a new base-level was achieved, south of the Khangai region. This is the Mongolian peneplane, above which the Khangai itself is a monadnock unit.

If, on the contrary, we assume that the two peneplanes are identical

FIGURE 149A.—The Arctic divide. The gently rolling character of the upland surface is well shown.

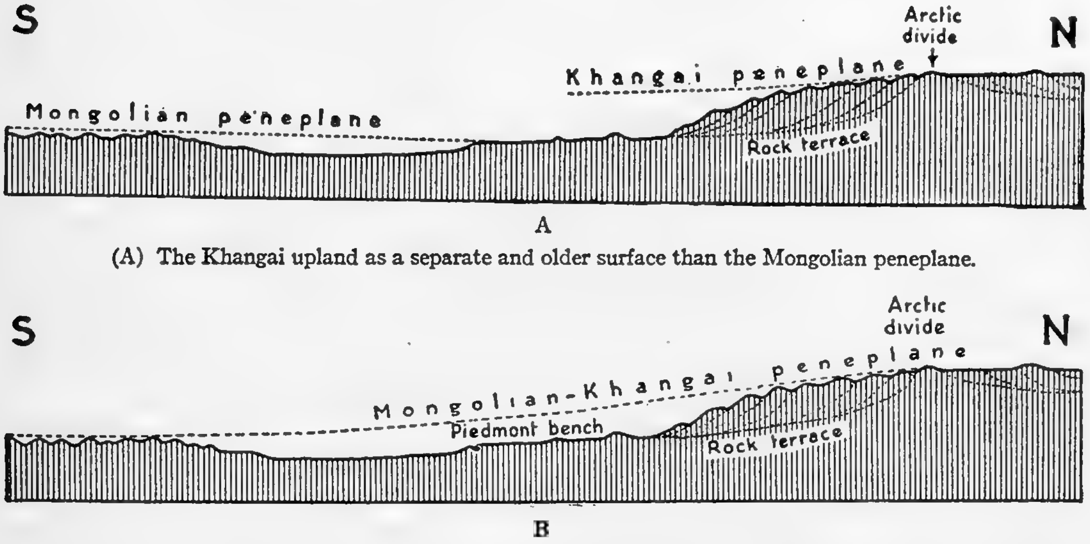
(Fig. 150, B), the significant steps may be summarized as follows: (1) There was a complex mountainous oldland; (2) the mountainous country was worn down to a peneplane which we have called the Mongolian peneplane; (3) the peneplane was warped and locally faulted, especially in the Altai and Trans-baikal regions, and was deeply dissected. In the Khangai Mountains the uplift was a very broad, gently sloped anticlinal warp, which was much higher than some of the other upwarped areas farther south.

The crux of the problem lies in the question of the age of the Mongolian peneplane. The oldest basin sediments are of late Mesozoic, probably Lower Cretaceous age. They rest upon a peneplane which was carved upon the old-rocks after the last mountain-folding. If the last folding took place, as we believe, in Middle Jurassic time, the mountains must have been reduced virtually to base-level by the beginning of the Lower Cretaceous (Comanchean). It seems very improbable that two major peneplanes, the Khangai and the Mongolian, could have been developed in this interval. If then the Mongolian peneplane is the surface on which the oldest Gobi sediments rest (Fig. 151, A), we should consider this an argument in favor of regarding the Khangai and Mongolian peneplanes as the same warped surface. But if the Mongolian be a much younger surface than the pre-Cretaceous peneplane, as suggested in figure 151, B, the question of the identity of the Khangai and Mongolian peneplanes would be reopened. Even in that case, the following considerations are opposed to the idea of there being two separate stages: (1) The Mongolian peneplane is as elaborately dissected as is the Khangai upland; if it were so much more recent it should be less dissected; (2) it can be shown that so much warping and faulting have taken place in Mongolia that an ancient upland peneplane might be expected to lie at very different levels in different parts of the country; (3) it seems to us that it is not logical to expect a great upland peneplane like the Khangai to survive the removal of the enormous quantities of hard rock, together with the long period of very slow decay and removal that must come in the later stages of post-mature dissection, involved in the carving of a new peneplane several thousand feet lower than the Khangai, over a large part of Mongolia.

FIGURE 149B.—Continuation of figure 149A. Showing the cirques which indicate an incipient glaciation.

Relations of the Mongolian peneplane and the Gobi erosion plane

The Mongolian peneplane always lies higher than the Gobi erosion plane that bevels the basin sediments, and there is no doubt that the Mongolian base-level is much the older of the two. The questions to be solved are the following: Is the surface that underlies the sediments in the gobis the down-



(A) The Khangai upland as a separate and older surface than the Mongolian peneplane.

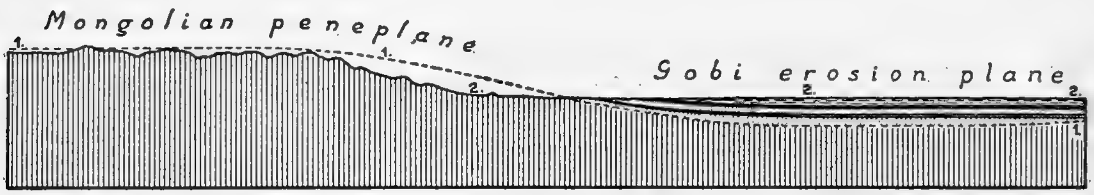
(B) The two planation surfaces as a single warped peneplane.

FIGURE 150.—The two diagrams show alternative explanations of the relations between the different planation surfaces developed on the ancient complex rocks.

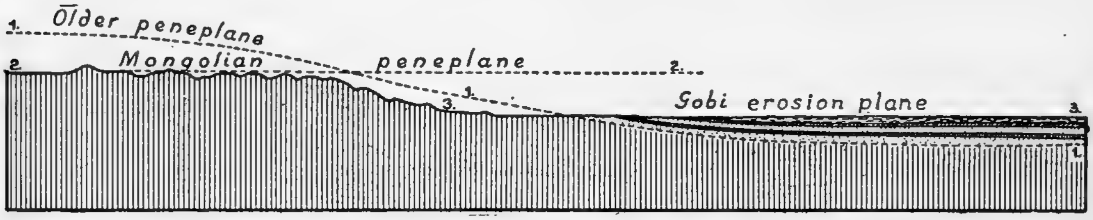
warped Mongolian peneplane (Fig. 151, A)? If not, at what date was the Mongolian peneplane completed?

The relatively thin fills of sediments, deposited at great intervals of time, seem to indicate that during each of these long periods in which no deposit was made, erosion might well have base-leveled the very moderately uplifted land from which the preceding sedimentary fill had been washed. It seems that in a region where epochs of slight warping and of quiescence have followed one another all through the late Mesozoic and Tertiary, a peneplane like the Mongolian might be made pari passu with the deposition of sediment. Hence, the Mongolian peneplane may not be of pre-Cretaceous age, but may have been completed at a much later time, say in the Middle Tertiary, and may have been finished at different times in different parts of the country.

The absence of Miocene sediments over most of the region studied by the Expedition, and over all or nearly all of northern China as well, rather suggests



(A) The warped Mongolian peneplane is represented as the surface on which the basin sediments rest.



(B) The Mongolian peneplane is represented as an additional and later product of erosion.

FIGURE 151.—The two diagrams illustrate alternative explanations of the ancient erosion surfaces developed on the oldrock floor.

the Miocene as a period of widespread erosion, in which the closing stages of peneplanation were completed. The great post-Oligocene disconformity, which is very striking everywhere except at Hsanda Gol, where the break between beds of Lower Oligocene and those of Lower Miocene age is inconspicuous, may correspond to the Mongolian peneplane developed on the hard rocks.

It seems possible that the peneplane may prove to be the surface upon which the oldest Lower Cretaceous sediments were laid down (Fig. 151, A); but if so, it could not be the surface upon which were deposited such sediments as the Ardyn Obo formation (Oligocene) and the P'ang Kiang formation (Miocene or later). It seems more likely that the pre-Cretaceous peneplane has been destroyed everywhere, except (1) where it is still covered by basin sediments (Fig. 151, B), or (2) where it has been reëxposed in comparatively recent time by the removal of its sediments. In this case, the Mongolian peneplane would be much younger than the pre-Cretaceous, and might have been completed in Tertiary time, perhaps in the Miocene.

The conditions under which the Gobi erosion plane was formed and the date of its completion are questions of some difficulty. Since late Pliocene beds are beveled by this surface at Hung Kureh, the plane must have been formed during the Pleistocene. Its recency is also attested by its extraordinarily smooth surface, undissected save for the hollows that represent the P'ang Kiang stage of erosion. Part of the difficulty lies in the question of how such widespread planation could have been accomplished in a region as uplifted as the interior of Asia must have been during the Pleistocene, which was undoubtedly a period of mountain growth.

Relations between the Gobi erosion plane and the lowlands of the P'ang Kiang stage

As there is no doubt that the P'ang Kiang hollows are younger than the Gobi erosion plane, the only problem is their mode of origin. We believe that the hollows are the result of combined action of wind and running water as explained on page 336.

COMPARISON OF PENEPLANES WITH THOSE OF SURROUNDING REGIONS

Mongolia is bordered by peneplaned mountain countries. Obruchev has described a very perfect upland peneplane beveling the mountains of western Dzungaria (1923, page 259). In a letter to us in 1925, he states that a similar peneplane is to be observed on all the mountains of Transbaikalia. Davis (1904, and 1905, pages 21–119) and Huntington (1905, pages 157–216) have described a well defined upland peneplane in Turkestan. To the south, in China, we have the classic work of Willis and Blackwelder, which establishes the presence of several erosion stages in China, the most ancient of which is an upland peneplane (Willis, 1907). We offer for brevity's sake the stages recognized by Bailey Willis as revised in part by Andersson:

1. The Pei T'ai stage (Early Tertiary). "We take this broad flat form to represent a stage of erosion to advanced old age, the nearest approximation to a peneplain which we have found in the course of our journey" (Willis, 1907, page 237).

2. "T'ang Hsien stage (Pliocene). Deposition of gravels and clays with the Hipparion fauna. Land forms of advanced maturity.

3. "Fen Ho stage (Early Pleistocene). Earth movements and subsequent revival of vertical erosion.

4. "Ma Lan stage (Middle Pleistocene). Cold arid climate. Deposition of valley gravels and æolian loess with *Elephas* sp." (Andersson, quoted by Yih, 1920, pages 65–77.)

5. "Pan Chiao stage (Late Pleistocene). Climate semi-arid, abundant summer rains. Dissection of the valley gravels and primary loess. Formation of redeposited gravels and loess, with *Bos* sp., *Ovis* sp. and *Cervus* sp." (Andersson, quoted by Yih, 1920.)

It is as yet too early to seek an actual correlation in physiographic stages; but those of China may tentatively be compared with the stages recognized in Mongolia, as follows, placing the most ancient stage at the bottom of the column:

China	*Mongolia*
8. Modern dissection	Modern dissection
7. Pan Chiao dissection	P'ang Kiang dissection
6. Ma Lan, loess stage 5. San Men pluvial epoch (valley gravels)	Gobi erosion plane and Pleistocene fans
4. Fen Ho uplift	Warping and uplift
3. T'ang Hsien, partial peneplanation	Rock terraces
2. Pei T'ai peneplane	Mongolian peneplane Khangai peneplane?
1. Monadnocks	Monadnocks

LAKES

Walther (1912, page 39) has classified desert lakes under three groups, as follows:

(1) Rain-fed lakes; (2) spring lakes; (3) terminal lakes, into which one or more rivers empty.

This classification applies rather to the water supply of the lakes than to their mode of origin. A little difference in rainfall for a few seasons would change a lake from one class to another. For example: the lake Ulan Nor, fed by the river Ongin Gol, is a terminal lake; but if a few dry seasons withered the Ongin Gol, the Ulan Nor would depend upon the rainfall and ground-water in the tectonic basin in which its shallow erosion hollow is carved. The Tsagan Nor, at the foot of Baga Bogdo, occupies part of a shallow erosion hollow in the floor of the tectonic basin (Plate XXX, in pocket). Its chief affluent stream, the Tatsin Gol, disappears at least ten miles west of the lake. The published maps show the Tsagan Nor as the terminal lake of the river Arguin Gol; but the Arguin Gol turns southeastward into another lake called Erin Nor. The Tsagan Nor is fed by vigorous springs in its base, but if several successive dry seasons should lower the level of the ground-water under the Tsagan Nor, this supply would be cut off, and the lake would depend chiefly upon rainfall.

The lakes of Mongolia are of widely diverse geologic origin, and many of them have had a complex and interesting history. The following types are known to be present, though the list is not exhaustive:

1. Lakes which occupy true fault-depressions, such as the Kosso Gol.
2. Lakes which occupy basins built by the heaping up of loose materials

so as to enclose a low area. Many ponds are found in hollows among sand dunes; and shallow lakes, or ponds, form along the advancing fronts of alluvial fans.

3. Lakes which occupy basins scoured out by some eroding agency.

(a) We have not seen lake basins due to the plucking and scouring of glaciers, but they should be present in the high Altai Mountains, west of the region explored by our Expedition.

(b) Plunge pools at the foot of waterfalls, and potholes excavated by swift torrents, are found in the high mountains.

(c) Crescent-shaped pools in the bends of drying rivers, and oxbow lakes in abandoned courses, are found along the larger streams.

(d) Small pools at springheads are not uncommon.

(e) The commonest of all lake basins in Mongolia is the desert hollow—a shallow basin due largely to wind work. This case receives special attention under the heading "Origin of desert hollows," page 336.

4. Lakes which occupy basins of a complex history, due partly to earth movements, partly to deposition of sediment, and partly to erosion. As an example of this type, we shall attempt to present the history of Tsagan Nor, one of the piedmont lakes of the Altai Mountains:

(a) There was a complex mountainous old land.

(b) It was peneplaned in pre-Cretaceous time.

(c) It was warped and somewhat eroded. In the warped basin and in erosion hollows in its surface, beds of Lower Cretaceous age were deposited. This step initiated a complex history of warping and deposition (described in Chapter XIII) which has lasted virtually to the present day, and which includes deposition of Oligocene, Miocene, Pliocene and Pleistocene beds, all somewhat deformed.

(d) A smooth erosion plane was carved, beveling the tilted and faulted sediments, in the course of which process a vast amount of material was removed. Sediments many hundreds of feet thick have certainly been eroded and exported from the region. In this sense an erosion basin of vast extent was formed; but whether it was an inland basin or had drainage connection with the sea at the time is an unsolved problem. The closing stages of the planation took place in the late Pliocene or post-Pliocene time.

(e) The erosion plane was warped, forming a tectonic depression which was further emphasized by the faulting that elevated the Altai front.

(f) The beveled sediments were scooped out by the wind, and a new lowland was made, which is the basin of the lake. Necessarily, since a deflation hollow cannot be excavated when standing water is present, the region must have been drier when the hollow was dug than it is now.

(g) In the deflation hollow a lake was formed which surely was much larger than the present Tsagan Nor. It extended eastward, probably to the Hung Kureh bluffs, and westward through what is now a great swamp.

(h) This larger lake has gradually diminished. We noted seven old beaches, the highest of which was twenty-nine feet above the water of the lake in 1922.

A careful analysis shows, therefore, that there are many stages in the development of the lakes of the Gobi region. The history here given is rather typical of the region; but each lake should be considered as an individual problem and many lake histories must be worked out in detail before a more sweeping generalization becomes possible.

The most common lakes seen in Mongolia are shallow playas in deflation hollows, which are dry most of the year. The short-lived streams wash silt into the lakes, where the material spreads out over the floor. When the lake is dry, this silt is bared for wind erosion, and almost every day clouds and whirling pillars of dust are seen rising from the dried playa beds. There is thus a direct correlation between the work of lakes and that of winds. Most lakes, including the more nearly permanent ones, are at least partially surrounded by sand dunes.

HUMMOCKS AND DUNES

The floors of the hollows and of the few river valleys that traverse the Gobi vary in condition from swamps to deserts. As a rule, the swampy parts develop a very uneven lumpy surface which is exceedingly difficult to traverse with motor cars. The hummocks are due to various causes. Grass and iris grow in thick clumps, so persistently that they form solid protuberances one to two feet high. Many kinds of low bushes or shrubs net the soil with their thick roots, and form a small hummock at the site of each plant. Rills tend to wash out the more loosely held soil around them, and the wind adds dust and sand to the hillock. Where drifting sand is available, lumps of these kinds may grow into sand-hummocks, as described on page 351. We gave the generic name "playatuft" to the plant-mounds of the playa-bottoms.

Mounds of another kind are made by a wrinkling of richly grassed turfy bottoms. In this case, the irregular surface is due to movements under the mat of turf, caused by freezing of ground-water (see Chapter IV, page 87), or by movement of saturated mud.

The wind-borne dust and sand form deposits of several types, depending upon the abundance and quality of the sand, the direction, strength, and constancy of the wind, the topography of the region, the rainfall, and the vegetation.

Where the supply of sand is abundant, true dunes arise on the lee-side of the source, and march in the direction of the wind. At the foot of Baga Bogdo, a long scimiter-shaped area of big dunes curves eastward for more than thirty miles from the dissected sediments and dry stream beds, which furnish the sand (Plate XXX, in pocket). The shape of the dunes varies with the wind. Most of the time, the westerly wind is so strong and constant that the dunes approach the shape of typical barchans. But during violent storms from the east, the shapes become sinuous and irregular, though the crestlines still lie rudely north and south, transverse to the direction of the prevailing winds.

It was our good fortune to cross the dune belt six times in 1922, twice during high winds which permitted observation of the movement of the sand. A thin sheet of sand-filled air leaped from the crest of the dune, like spray from the crest of a big sea wave. The sand spray dropped upon the leeward side of the dune, down which it ran in long rills that looked like a syrup spilling down the face of the dune. New rills started from the crest, or near it, every few seconds. We looked for eddies on the leeward side, and saw some, but they were small, and were not important factors in shaping the advancing front of the dune. The chief factor was the simple delivery of sand from the back slope to the front.

With less abundant supply, the sand forms thin sheets over the level surfaces, especially on the upland above the valley, or hollow, from which the sand comes. It climbs the windward slopes of hills, blanketing them against effective wind-erosion.

The growing vegetation entraps the drifting sand, growing as the sand accumulates, until low hillocks are built up. They are probably similar to the "tamarisk mounds" described by Huntington (1907 *a*, page 179), and should be clearly distinguished from true sand dunes built by the wind, even though dunes may be invaded by plants and fettered by their roots. In the case of these sand hummocks, on the contrary, the plants were on the ground before the sands. Layer by layer the sand is entrapped and held. As the hillock grows, other plants join the colony. Thus a hillock may be started by grass, or peas, and when it has attained a fair round convexity, the "dune plum" may gain a roothold, and may replace the original plants. Or the hillock may be mothered by dune plums from the beginning. In suitable places, the sage, or more rarely, the saxaul or the tamarisk, may start the hillock, which commonly grows about three to five feet high, though ten feet has been noted. Internally, these hummocks are made of thin, nearly horizontal beds, faintly arched; the convexity of the beds is less than that of the hill.

CHAPTER XX

STRATIGRAPHY OF THE LATER SEDIMENTS

ONLY the formations from which fossils have been collected are of service in the present discussion. There are many basins of sediments which have not yet yielded fossils, but we shall not consider them here.

The record of the beds of gravel, sand, and clay which have been laid down on the floor of the Gobi basin in the past has an important bearing upon many other large problems. For example, an attempt to read the climates that prevailed during past ages in Mongolia requires consideration of the kinds of sediments deposited during each period and the arrangement of their strata. Another question, which the study of the sediments helps to decide, is whether Mongolia has always been a great inland basin or whether its rivers ran to the sea until comparatively recent times. The sedimentary record helps us to answer yet another large problem: does the weight of sediments tend to press down the earth's crust, and does that sinking of the crust tend to push up mountain ridges along the margin of the sediment basins?

THE LATE MESOZOIC ERA

The complexly folded oldrock floor of Mongolia includes early Mesozoic strata which we consider to be Jurassic (Chapter XVII). The earliest sediments which lie unconformably upon the oldrock floor bear fossils of Lower Cretaceous age. The great break between the earlier and the later Mesozoic formations marks a change in the physical history of central Asia (Chapter XXII); and the deposition of the late Mesozoic sediments marks the initiation of basin history, with which also begins the record of vertebrate palæontology in central Asia.

CRETACEOUS DEPOSITS

Five formations of Cretaceous age have been distinguished and given locality names. They are the Ondai Sair, Oshih, Iren Dabasu, Wan Ch'uan, and Djadokhta. It is not yet possible to determine their detailed structural or their exact time relations. In all probability no two are physically continuous throughout, and probably no two are of precisely the same age, but it is likely that some of the horizons overlap one another. We do not assume, therefore, in using these formational terms, that they are each of equal independent significance in the geologic column. They are each distinct enough physically and geographically and even palæontologically to warrant retention of the field terms, and they have been arranged in the sequence suggested by the palæontologists who have studied their respective faunas.

The determinations of faunas have been made by Cockerell, Granger, Gregory, Matthew, Mook, Osborn, and Simpson. The suggested ages and correlations of the strata are chiefly the work of Matthew and Osborn, who consider the correlations to be tentative, and subject to revision as more fossils are collected and studied.

The Ondai Sair formation

The Ondai Sair type locality is the reëntrant of sediment on the east side of the Mount Uskuk block, about seventy-five miles west of Oshih, and about forty-five miles north of the Altai range, Baga Bogdo (Fig. 110, page 242, and Plates XXVII, XXVIII, in pocket). The formation includes gray sandstones and dark paper-shales, with a few beds of red sandy clay. Like the Oshih, the Ondai Sair formation is disturbed by faulting and tilting. The upper limit is an erosion plane on which rests the basal conglomerate of an early Tertiary formation. The whole thickness must exceed five hundred feet, as the base is not exposed where the section was measured. The details of the section and the list of the fauna have been included in the description of Cretaceous strata, in Chapter XIII, page 230.

The correlation of these beds will be discussed after the Oshih formation has been described.

The Oshih (Ashile) formation

The type Oshih section is in Oshih hollow, about twenty-five miles north of Artsa Bogdo of the Altai mountain system. The Oshih formation includes the oldest of the later sediments lying upon the complex oldrock floor of Mongolia. The base of the formation is covered, the top has been eroded away, and the remnant which is exposed in Oshih hollow is much disturbed by faults, so that nowhere can a complete section be seen. The sequence has been unraveled by studying the faults and determining which is the older upthrown group and which the younger downthrown group along each fault. Combining these groups, we have in the eastern and southern badlands the following sequence:

1. The "cannonball" group of sandstones and sandy clays, the "*Psittacosaurus* beds."

2. A group of red clays and thin sands.

3. A group of pink and buff clays.

4. The lava flow.

5. A gravel member of rather uncertain relations.

6. A group of brown clays, the "*Asiatosaurus* beds."

7. A group of gray, thin-bedded shales and sands, with fresh-water limestones.

8. A fine red siliceous sand, the Sairim formation, found on the upland northeast of the hollow.

The fauna thus far collected includes fresh-water bivalve shells and three dinosaurs—a primitive predentate, *Psittacosaurus*, a large sauropod, and a theropod.

The palæontologists agree that the *Protiguanodon* found at Ondai Sair, and the *Psittacosaurus* of Oshih are very closely related, if not identical genera. The similarity in lithologic habit and the presence of the peculiar paper-shales at both places further suggest that the two formations are of approximately the same age. They lie in the piedmont basins of two adjacent mountain ranges, Baga Bogdo and Artsa Bogdo, and are probably in physical continuity with one another. Cockerell (1924) considers the Ondai Sair to be of essentially the same age as the fish-bearing shales of Transbaikalia. Grabau correlates the Ondai Sair with the fish-bearing shales of Kansu, Shensi, and Shantung, and with the Kweichow formation of Honan (Grabau, 1923 *a*, *b*, and *c*).

The faunas, including those of the paper-shales of Siberia and North China, are all of an inland type, and are very difficult to assign to a definite place in the geologic column. Reis (1910), after discussing evidences suggesting correlations which range from Jurassic to Lower Tertiary, doubtfully assigned the Siberian faunas to the Upper Jurassic. Cockerell, after critically considering Reis's Siberian biota and the Ondai Sair fauna, concludes "it presumably belongs to a period near the beginning of the Lower Cretaceous, and its classification as Jurassic or Cretaceous may be merely a matter of arbitrary definition" (1924, page 135). Grabau's revision of the entire subject, in view of the discoveries of similar or related faunas in China, will be awaited with great interest.

The structural relations of the Oshih and Ondai Sair formations must be taken into account in any attempt at correlation. The formations rest directly upon the oldrock floor, and mark the very beginning of "basin-history," as we have explained in Chapter XVII, page 289. The youngest folded rocks in the oldrock floor, beneath the great unconformity, are the conglomerates and sandstones which we have considered to be Jurassic. The great structural break between the two series of beds renders it unlikely that both could be Jurassic, and rather supports the suggestion that the unconformity should be used to mark the separation of two periods.

The Iren Dabasu formation

The Iren Dabasu formation is exposed in a low, dissected platform, along the southern side of the saltpan, Iren Dabasu Nor, or Shaya Nor (Plate XXIII, in pocket). Slate hills, cut by granite, limit the basin on the north and form the oldrock floor which slopes gently southward under the Cretaceous sediments. The floor is not smooth, as low ridges of granite and of quartzite rise through the sediments. The Iren Dabasu beds are favorably exposed in two places, which we called, respectively, the eastern and the western areas.

In both areas, the strata consist of red and gray sandy clays and coarse gray sandstones. In general, the clays occupy the lower part of the section and are well bedded, with marked color zones. The dinosaur bones found in them are less scattered than in the sandstones; many partial skeletons were unearthed with the bones in articulated skeletal position. These facts suggest quiet deposition, either on broad flood plains or, more probably, in shallow lakes. The details of the sections are given in Chapter XI, page 203. The fauna includes iguanodonts of several sizes, which are very abundant, as well as numerous remains of "ostrich dinosaurs" and deinodonts. Fragments of dinosaur eggs are so plentiful at one place as to suggest our field name, "dinosaur-rookery." One sandstone bed carries abundant shells of a fresh-water mollusk, not yet studied. The correlation of the dinosaur beds at Iren Dabasu must await a detailed study of the fauna. W. D. Matthew considers the fauna to be rather primitive, and holds that it is best to place the Iren Dabasu tentatively in the Lower Cretaceous (personal communication).

The Wan Ch'uan formation

Another pre-Tertiary basin lies in the passes north of Kalgan (Fig. 5, page 47). Its sediments are exposed in the very edge of the Mongolian basin and are over five thousand feet thick. The lower three thousand feet of rock consist of coarse pebbles, chiefly of trachyte and granite porphyries. The conglomerates grade upward into finer sands and clays, in which scattered dinosaur bones have been found. The strata are tilted toward the north and dip as much as thirty degrees, especially near the faults which cut the basin at several places. The average dip is about ten degrees. The cross-bedding dips northward, indicating currents flowing from the south. The Wan Ch'uan beds are overlaid by Tertiary basalts and associated sediments which form the top of the Mongolian plateau at this point. The basin is of great extent and splendidly exposed, and a thorough examination of it should yield a rich harvest of discovery.

UPPER (?) CRETACEOUS DEPOSITS

The Djadokhta formation

As one comes eastward from Oshih, the first recognizable beds of the Djadokhta are encountered about forty miles from the last identified outcrops of the Oshih. The formation is about five hundred feet thick. The sand grains are moderately well rounded, exquisitely fine, and of uniform size, averaging 0.1mm. and smaller. While the great majority are of quartz, some are of chalcedony and jasper, and a few are of feldspar, chiefly microcline. There is a very loose binder of calcite which fails to fill all the interstices. The vertical cliffs, shown in Plate I, are massive and structureless, and are composed wholly of fine red sand. We believe that wind-borne sand was entrapped by a sparse vegetation, which grew upward as the sand accumulated and so built up a thick, uniform deposit resembling loess. Some strata show cross-bedding of æolian type, in which the sloping beds dip as much as twenty-four degrees and range from fifteen to fifty feet in length (Plate I and Fig. 152). They indicate the presence of large sand dunes in Djadokhta time. On the

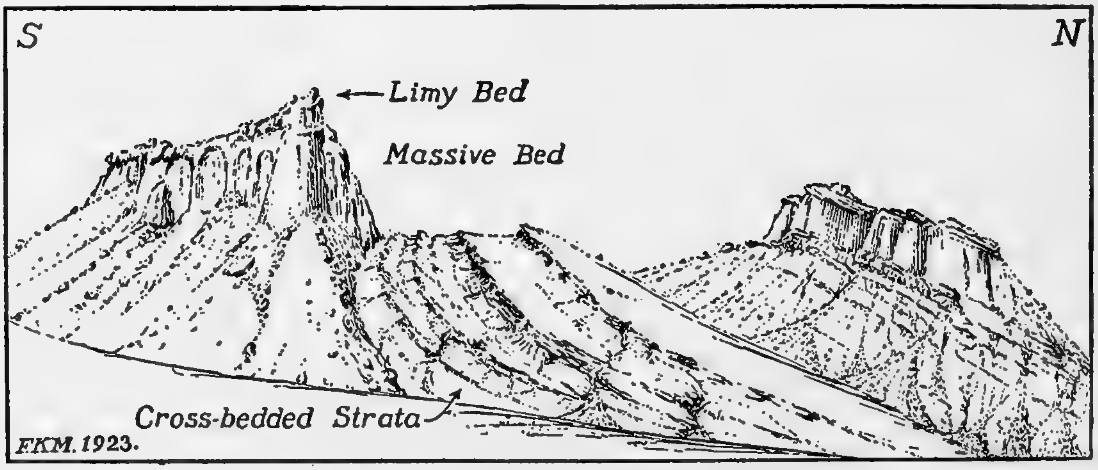


FIGURE 152.—Æolian cross-bedding at Djadokhta.

other hand, the concretionary beds are horizontal, and some of the larger ones can be traced for as much as three miles (Plate I). Where the limy or marly matter exceeds the sand, the rock becomes almost a limestone. This fact favors the inference that at least the broader marly beds were deposited in shallow ponds, rather than the view that they are limy concretions, developed at a former ground-water level.

There are very few beds of deep red clay which outcrop in the form of lenses. We examined the clays for plant remains, but found none. Large pebbles of dense hard materials, chiefly jasper, quartzite, and vein quartz, are found lying isolated, here and there, in the beds of fine sand. They are all faceted pebbles with very well-rounded interfacet edges, and are polished to a waxy luster. The fine grain, the uniformity of texture in virtually all the sand beds, the great predominance of quartz grains, the paucity of feldspar, the very few beds of clay,—all these facts support the inference that the Djadokhta beds were derived from the erosion of an older sandy sediment, possibly the Oshih, which once may have covered the site of the Gurbun Saikhan range. The scattered pebbles, too, were probably derived from some older pebbly sediment rather than from the crystalline rocks of the Gurbun Saikhan range. But the pebbles were probably faceted and polished in Djadokhta time, when wind-blown sand was abundant.

The fauna thus far recorded include the following:

Mammalia
- *Djadochtatherium matthewi* Simpson (1925)
- Several other rare primitive mammals, as yet undescribed.

Reptilia
- Dinosauria
  - Predentata
    - *Protoceratops andrewsi* Granger and Gregory (1923)
    - A larger predentate, either ceratopsian or iguanodont
  - Armored dinosaur, undescribed
  - Theropoda
    - *Velociraptor mongoliensis* Osborn (1924*c*)
    - *Saurornithoides mongoliensis* Osborn (1924*c*)
    - *Oviraptor philoceratops* Osborn (1924*c*)
- Crocodilia
  - *Shamosuchus djadochtaensis* Mook (1924)
- Lacertilia
  - Two undescribed forms

COMMENTS ON CRETACEOUS SEDIMENTS

All the formations thus far examined bear evidence of having had a greater areal extent in the past; in the Altai region the evidence suggests that certain deposits once covered the site of the mountain ranges. All the deposits are somewhat disturbed and warped. Some, like the Oshih, Ondai Sair, and Wan Ch'uan, are faulted and tilted. The Oshih and Wan Ch'uan formations indicate that the country had a rugged relief in the region where they were deposited, and possibly a relief whose height was renewed from time to time by earth movements during the deposition. Most of the formations, however, indicate moderate or low relief. None of them grades into the formation which lies directly above or beneath it. The faunas, too, are sharply distinct from those of the overlying or underlying sediments. These facts indicate either that there are time intervals unrecorded by sediments, or else that many basins yet remain to be discovered. Locally, at least, the first interpretation is the correct one,—if other Cretaceous horizons are to be found, they will not be found in sequence with the known formations. For example, the Djadokhta is directly succeeded by Paleocene beds; the Iren Dabasu by Middle or Upper Eocene; the Ondai Sair by Oligocene, and the Wan Ch'uan by basalts and interbedded clays which Andersson considers to be Oligocene. The discontinuity of sediments and of faunas is a very striking fact. The faunas all consist of new types, and bear marked evidences of isolation, suggesting that central Asia was shut off from Europe and America during a great part of Cretaceous time.

THE CENOZOIC ERA

The Cenozoic deposits include at least ten formations from which fossils were recovered in 1922 and 1923. They differ from the Mesozoic deposits in their complete lack of dark carbonaceous beds and in their generally less indurated and less disturbed condition.

PALEOCENE PERIOD

Only one formation, the Gashato, was found which could be assigned tentatively to the Paleocene period.

The Gashato formation

The earliest post-Cretaceous deposit of which we have record is the Gashato formation, which directly overlies the Djadokhta beds, at the foot of the Gurbun Saikhan range. It begins at the base with four to six feet of coarse gravel composed of angular pebbles of the ancient rocks of Gurbun Saikhan. A group of sandy clays, mostly of deep red and chocolate brown colors, about one hundred feet thick, follows the gravel; then come fifty feet of sands and gravels and a small lava flow twenty feet thick, above which are reddish sands and clays. The basin extends at least fifty miles to the eastward from the type locality at Gashato, which lies seven miles southeast of Djadokhta (Fig. 98, page 194). The total thickness of the beds must exceed the measured sections. The fauna determined by Matthew and Granger (1925*a*) is as follows:

Mammalia
- Notoungulata
  - *Palæostylops iturus* Matthew and Granger
- Multituberculata
  - *Prionessus lucifer* Matthew and Granger
- Glires
  - *Baënomys ambiguus* Matthew and Granger
- Menotyphla?
  - *Eurymylus laticeps* Matthew and Granger
- Condylarthra?
  - *Phenacolophus fallax* Matthew and Granger
- Creodonta
  - *Hyracolestes ermineus* Matthew and Granger
- Uncertain, creodont or carnivorous marsupial?
  - *Sarcodon pygmæus* Matthew and Granger

Reptilia
- Chelonia
  - Fragments of an emydid turtle.

EOCENE PERIOD

The Arshanto formation

The Arshanto formation consists chiefly of fine, almost structureless, hard red clay which, on weathering, breaks up into chips and "crumbs." It is possibly a wind-borne deposit, similar to loess. In the Houldjin bluffs its horizon is represented by red clays and olive green, fine, fissile shales, which are undoubtedly lake deposits.

The only fossil thus far described is a small lophiodont, *Schlosseria magister* (Matthew and Granger, 1926). None of the typical Irdin Manha fossils has been obtained from the Arshanto. The contact between the two formations, where it has been studied, is clearly an erosion plane. Probably the break between the two is much less significant than most of the other gaps in the sedimentary record in Mongolia, yet it seems advisable to separate the Arshanto from the Irdin Manha because of its notably different physical and faunal aspect, and because of the clear-cut boundary between the two formations.

The Tukhum formation

A hard red clay, physically resembling the Arshanto, underlies the Shara Murun beds, at the type locality of the latter formation, more than one hundred miles southwest of Irdin Manha. It seemed best to call these red beds by a new name, as they differ notably from the Shara Murum. Accordingly, they were called the Tukhum beds, from the broad lowland in which they are exposed.

Matthew and Granger (1926) have described a small hyracodont, *Teilhardia pretiosa*, from the red clay. According to the opinion of these authorities, *Teilhardia* may be ancestral to *Ardynia* of the Oligocene Ardyn Obo formation. They add that possibly the Tukhum formation may be as young as the Irdin Manha.

The Irdin Manha formation

The unit which succeeds the Arshanto consists of brown, red, and gray soft clays, with associated beds of gray sand and gravel. In general, the coarser beds are above the clays. The sand and gravel fill shallow channels in the clay. There are a few thin and local beds of exquisitely fine and powder-like sand. There are broad lens-shaped beds of sand with streaks of gravel and clay, as well as cross-bedded gravels and coarse sands with foreset beds three and four feet long. All these facts point to varying conditions of deposition, such as might be expected on a broad flood plain or in a large, low alluvial fan. The fauna has not been fully studied as yet; it includes eight genera of cursorial carnivores, one of which was bigger than the Kodiak bear; at least nine perissodactyls, all of which were ranging, browsing forms, chiefly titanotheres and lophiodonts; and at least four artiodactyls. Turtle bones are abundant, and a few fish vertebræ were found. The fauna is neither a strictly forest-dwelling group, nor a true desert fauna, but rather belongs to open plains which bear patches of trees along the stream courses. Several of the types have wandered in from America, while others represent types which later migrated to America and Europe. W. D. Matthew considers the Irdin Manha to be comparable to the Bridger of North America.

Mammalia
- Carnivora
  - Mesonychidæ
    - *Andrewsarchus mongoliensis* Osborn (1924*e*)
    - ? Gen. indet., resembling *Harpagolestes.*
    - *? Synoplotherium* sp. gen. indet.
    - *Hapalodectes serus* Matthew and Granger (1925*e*)
    - *? Hapalodectes auctus* Matthew and Granger (1925*e*)
  - Hyænodontidæ
    - *Paracynohyænodon morrisi* Matthew and Granger (1924*a*)
    - *Hyænodon irdinensis* Matthew and Granger (1925*e*)
    - *Propterodon irdinensis* Matthew and Granger (1925*e*)

Mammalia—*Continued*
Carnivora—*Continued*
Miacidæ
Miacis invictus Matthew and Granger (1925*e*)
Rodentia
? Paramys
Undetermined fragments
Perissodactyla
Helaletidæ?
Teleolophus medius Matthew and Granger (1925*f*)
Desmatotherium mongoliense Osborn (1923*b*)
Desmatotherium fissum Matthew and Granger (1925*f*)
Hyracodontidæ
Cænolophus proficiens Matthew and Granger (1925*f*)
Lophiodontidæ
Lophialetes expeditus Matthew and Granger (1925*f*)
Lophialetes minutus Matthew and Granger (1925*f*)
Titanotheriidæ
Protitanotherium grangeri Osborn (1925)
Telmatherium berkeyi Osborn (1925)
Dolichorhinus olseni Osborn (1925)
Manteoceras ? irdinensis Osborn (1925)
Metarhinus ? mongoliensis Osborn (1925)
Chalicotheriidæ
(doubtful specimen)
Amblypoda
Eudinoceras mongoliense Osborn (1924*d*)
Artiodactyla
Helohyidæ
Gobiohyus pressidens Matthew and Granger (1925*e*)
Gobiohyus orientalis Matthew and Granger (1925*e*)
Gobiohyus robustus Matthew and Granger (1925*e*)
Achænodont, indet.
Tragulina
cf. *Archæomeryx*, gen. indet.
Insectivora
? Pantolestes sp.
Aves
Undetermined fragments of tarso-metatarsus.
Reptilia
Chelonia
Trionychid turtles
Pisces
Undetermined vertebræ

The Shara Murun formation

The beds at Shara Murun lie in the gobi which contains the Irdin Manha, but are considered to be of somewhat later Eocene age than the Irdin Manha (Figs. 100, page 199, and 156).

The section is at least three hundred feet thick and includes a group of soft clays of many colors,—brown, deep red, purple, greenish-gray, and mottled. They rest upon the hard red clays of the Tukhum formation, and are overlaid by light gray sands and gravels. Bones are abundant and well preserved in the clays, and nearly complete skeletons were unearthed. Gypsum crystals are present at several places along the bluffs, and at these places no fossils have been found. Only scattered bones were seen in the sandstones. The faunal list, so far as it is worked out, follows:

Mammalia
- Carnivora
  - ? Mesonychidæ
    - *Olsenia mira* Matthew and Granger (1925*d*)
  - Hyænodontidæ
    - *Pterodon hyænoides* Matthew and Granger (1925*d*)
- Rodentia
    - *? Desmatolagus*
- Perissodactyla
  - Helaletidæ
    - *Deperetella cristata* Matthew and Granger (1925*d*)
  - Hyracodontidæ
    - *Cænolophus promissus* Matthew and Granger (1925*d*)
    - *Cænolophus obliquus* Matthew and Granger (1925*d*)
    - *Cænolophus progressus* Matthew and Granger (1925*d*)
    - *Cænolophus ? minimus* Matthew and Granger (1925*d*)
  - Amynodontidæ
    - *Amynodon* (or new genus)
  - Titanotheriidæ
    - *Protitanotherium mongoliense* Osborn (1925)
    - *Protitanotherium andrewsi* Osborn (1925)
    - *Dolichorhinus kaiseni* Osborn (1925)
  - Chalicotheriidæ
    - (doubtful specimen)
- Artiodactyla
  - Hypertragulidæ
    - *Archæomeryx optatus* Matthew and Granger (1925*d*)

Reptilia
- Chelonia
    - Tortoise, undescribed.
    - Trionychid turtles, undescribed.

OLIGOCENE PERIOD

The Ardyn Obo formation

At Ardyn Obo, about ninety miles northwest of Shara Murun (Fig. 83, page 175), the Expedition stopped in 1922 and 1923 to examine a scarp of well-exposed sediments. It lies at a corner of the cliff, which extends southward along one front and southwestward along the other (Fig. 84, page 176). The cliff itself is nearly three hundred feet high, and the slopes below it add another two hundred feet. The sediment rests directly upon the granite and gneiss of the oldrock floor.

The lowest beds exposed in the floor of the lowland are red clays, followed by light gray clays in which a titanothere skull was found. Red clays appear at the base of the bluff, and are succeeded by gray clays, passing upward into one hundred and fifty feet of cross-bedded sand and gravel, the foreset beds of which dip toward the northeast and north. In the upper gravels, polished pebbles are found, though they are not as lustrous as those of Irdin Manha. A partial list of the fauna follows:

- Mammalia
  - Carnivora
    - Hyænodontidæ
      - *Hyænodon eminus* Matthew and Granger (1925*b*)
    - Oxyænidæ
      - *Ardynictis furunculus* Matthew and Granger (1925*b*)
    - ? Canidæ
      - *? Cynodictis*
  - Rodentia
    - *Ardynomys olseni* Matthew and Granger (1925*b*)
    - *Ardynomys chihi* Matthew and Granger (1925*b*)
    - *Desmatolagus robustus* Matthew and Granger (1925*b*)
  - Perissodactyla
    - Helaletidæ?
      - *Colodon inceptus* Matthew and Granger (1925*c*)
      - *Paracolodon curtus* Matthew and Granger (1925*c*)
    - Hyracodontidæ
      - *Ardynia præcox* Matthew and Granger (1923*b* and 1925*c*)
      - *Cadurcotherium ardynense* Osborn (1924*f*)
    - Titanotheriidæ
      - *Brontops gobiensis* Osborn (1925)
      - *Menodus mongoliensis* Osborn (1925)
    - Chalicotheriidæ
      - *Schizotherium avitum* Matthew and Granger (1923*b* and 1925*c*)
  - Amblypoda
    - Gen. indet.

Mammalia—*Continued*
- Artiodactyla
  - Anthracotheriidæ
    - Gen. indet.
  - Hypertragulidæ
    - *Lophiomeryx angaræ* Matthew and Granger (1925*c*)
    - *Lophiomeryx gobiæ* Matthew and Granger (1925*c*)
    - *Miomeryx altaicus* Matthew and Granger (1925*c*)

Reptilia
- Chelonia
  - *Testudo insolitus* Matthew and Granger (1923*b*)
  - Emydid, gen. indet.
  - Trionychid, gen. indet.

The Houldjin formation

The top of the Houldjin bluff, south of Iren Dabasu, is capped by a soft, friable, yellow gravel, the lower parts of which are loosely cemented in places. The pebbles are chiefly vein quartz, with quartzite, chalcedony, graywacke, argillite, and other hard, durable fragments. Many pebbles are well rounded, especially those of quartz, but others are angular. At the type section, the gravel is only fifteen feet thick, but southward it increases to at least forty feet. Fossils are abundant, but all are fragmentary. Many bones are so well worn that the edges of fractures are rounded. The following have been collected (Matthew and Granger, 1923*a*).

Mammalia
- Carnivora
  - Undetermined fragments.
- Perissodactyla
  - *Baluchitherium* sp.
  - *Cadurcotherium* sp.
  - *Cœnopus* or
  - *Præaceratherium* sp.
- Artiodactyla
  - *Entelodon dirus* Matthew and Granger

Reptilia
- Chelonia
  - Fragments of a large tortoise.

The Hsanda Gol formation

In the great gobi at the northern foot of Baga Bogdo, there are exposed at least 3,500 feet of early Tertiary sediments, overlying the Lower Cretaceous

Ondai Sair formation. There is a basal conglomerate of well-rounded pebbles, grading upward through finer gravels and sands to a series of clays. A basalt flow divides the formation into an upper and a lower member. At the Tatal Gol (Plate XXIX, in pocket), the lava flow dies out, and here no clear distinction could be drawn between the upper and the lower beds.

All of the Hsanda Gol fossils at the type section came from the red and brown clays above the lava flow. At the Tatal Gol, however, Mr. Granger reports finding fossils below the horizon corresponding to that of the basalt. The list of fossils thus far studied is given in Chapter XIII, page 234.

MIOCENE PERIOD

The Loh formation

Directly overlying the Hsanda Gol clays, about five miles south of Uskuk Mountain, there is a group of olive green clays less than one hundred feet thick. No clearly defined physical break can be seen between the two formations, but the upper olive clays yielded fossils which Dr. W. D. Matthew correlates with the Lower Miocene of Europe. The name of this place is Loh, which, the Mongols told us, means dragon, and refers to the presence of the "dragon bones" in the clays. Accordingly, the clays were called the Loh formation (Plate XXVIII, in pocket). A list of fossils will be found in Chapter XIII.

The strata dip southward at a very slight angle, which should bring them underneath the white sands and light gray clays that outcrop ten miles farther south (Plate XXIX, in pocket, and Fig. 107, page 229). No fossils were found in the southern beds, but they must occupy a position intermediate between the typical Loh horizon and the Pliocene beds of Hung Kureh, which outcrop still farther south.

PLIOCENE PERIOD

The Hung Kureh formation

Southeast of Tsagan Nor, at the foot of Baga Bogdo (Plate XXX, in pocket, and Fig. 107, page 229), there is a bold white scarp, facing west and north. Near the base of the scarp, the lowest beds exposed are yellow sands which contain fossils. Above them are fine white sands and light gray clays, forming the face of the bluff, which is about two hundred feet high. The clays and sands are abruptly succeeded by a rubble of coarse pebbles which are only slightly rounded. The contact between the clays and sands and the overlying rubble is sharp, and tentatively we regard it as marking the upper limit of the typical Hung Kureh. It undoubtedly indicates a change in physical conditions in the region. A list of fossils will be found in Chapter XIII.

In the valley of the Da Ying Gol, south of Hung Kureh (Plate XXX, in pocket), we studied a succession of gray and light brown clays and sands which yielded small gastropods and plant fragments. The relation between them and the typical Hung Kureh beds could not be definitely determined because of covered ground and the fact that both formations are disturbed by tilting, faulting, and even a moderate folding. Therefore, the southern beds were named the Da Ying Gol beds. They can be traced southward to the "West Knolls" (Plate XXX, in pocket), within three miles of the Altai front, and retain their character of fine clays, brown, red, and gray colors predominating. Small black nodules of oxide of manganese and abundant gypsum crystals are found in the clay at the West Knolls.

It is probable that the Da Ying Gol and the Hung Kureh are the same formation, and for the present the name Hung Kureh will cover both groups. It is impossible to state the thickness of the Hung Kureh, as the base is not exposed, but it exceeds three hundred feet without including the Da Ying Gol. If the latter be added, it will exceed 1,000 feet.

SUMMARY OF THE CRETACEOUS AND TERTIARY DEPOSITS

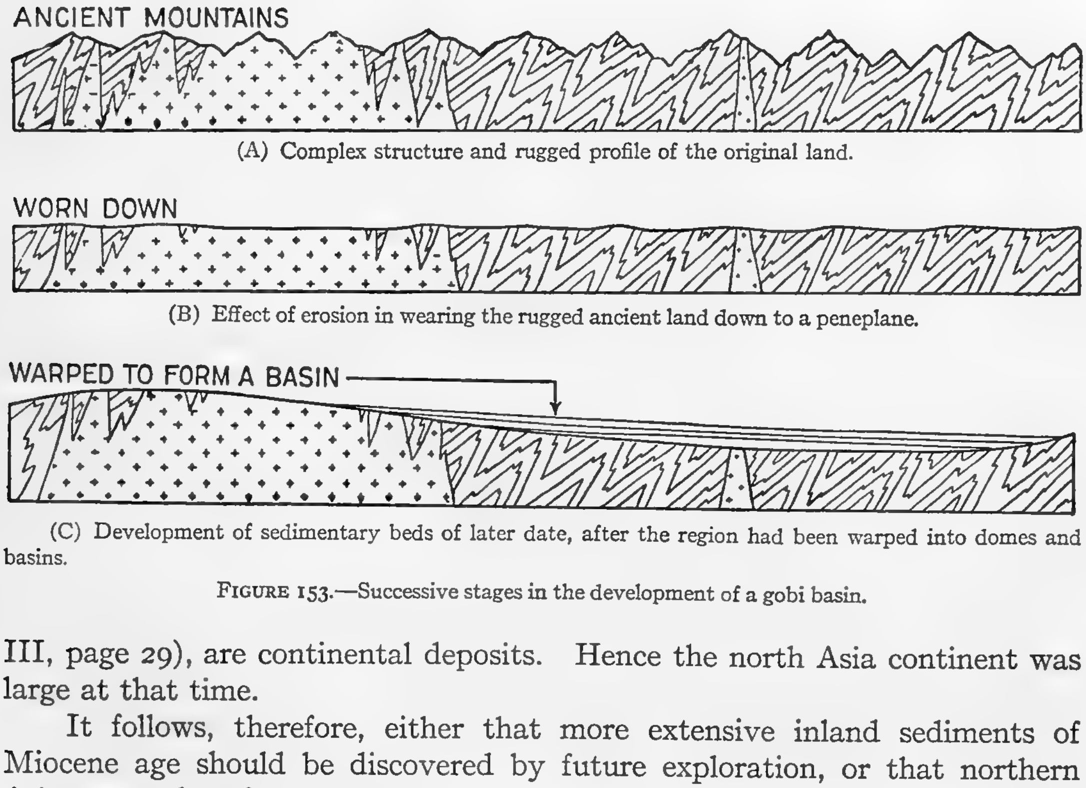
Among the interesting facts which the Cretaceous and Tertiary deposits bring to light are the following:

All the deposits are relatively thin. The fact that the actual thickness in most cases exceeds the measured thickness of a visible section is somewhat compensated by the evidence of structural geology, which implies that most of the gobis of the Iren tala are shallow. Those of the Tsagan tala, along the foot of the Altai, are deeper, but the evidence collected between Mount Uskuk and Baga Bogdo implies that the combined thickness of all formations there does not much exceed 10,000 feet; and these formations range from Lower Cretaceous to late Pliocene.

The large gaps in the record are very noticeable (Berkey and Morris, 1924*b*). No period of geologic time is represented by any approach to a complete section. For example, the three best represented periods are the Cretaceous, Eocene, and Oligocene. Of the Cretaceous, we have three horizons: (1) The Oshih-Ondai Sair, which, according to Grabau, is about equivalent to the Wealden. (2) The Iren Dabasu and Djadokhta beds, which, though clearly later than the Oshih, are very difficult to correlate with American or European horizons. They carry primitive faunas, and cannot be later than early Upper Cretaceous. (3) The greater part of Cretaceous time is unrecorded in the known Cretaceous sections of Mongolia. The

Eocene is represented by the Paleocene Gashato, the Middle Eocene Arshanto, and Upper Eocene Irdin Manha and Shara Murun formations, which surely leave out most of the Eocene period. The three Oligocene horizons,—Ardyn Obo (Lower Oligocene), Hsanda Gol (Middle Oligocene), and Houldjin, (Middle Oligocene)—cover more or less of the lower and middle parts of the period.

The gaps in the record of other periods are still greater, as only one horizon has been found for the Miocene and one for the Pliocene. The only Miocene beds yet seen in Mongolia are those of Loh. Similarly, in China, Andersson cites no positively determined Miocene formations, but refers a few beds to the "Lower Pliocene or Upper Miocene" (Andersson, 1923*a*, Table II). This almost complete absence of the Miocene over vast areas of basin lands constitutes one of the major problems of the region. No marine Miocene beds are known in northern Asia; even within the Arctic circle, the Miocene lignites reported by Baron von Toll (1900, quoted by Suess, 1902,



(A) Complex structure and rugged profile of the original land.

(B) Effect of erosion in wearing the rugged ancient land down to a peneplane.

(C) Development of sedimentary beds of later date, after the region had been warped into domes and basins.

FIGURE 153.—Successive stages in the development of a gobi basin.

III, page 29), are continental deposits. Hence the north Asia continent was large at that time.

It follows, therefore, either that more extensive inland sediments of Miocene age should be discovered by future exploration, or that northern Asia was undergoing general erosion during that period.

The suggestion made by the patchy distribution of all the post-Jurassic basin sediments is that they are all inland deposits. Despite the intermittent warping which accompanied the sedimentation, the continent, as a whole, was stable and was undergoing removal rather than deposition of sediments during the late Mesozoic and the entire Cenozoic eras.

For the Pleistocene, we have the Olan and Diske beds, which Andersson has named (1923*a*, pages 45–47), and the tilted rubbles of Gochu ridge that overlie the Hung Kureh. Except along the foot of the Altai, however, we know of no other deposits of this period in the great basin of the Gobi. In this respect, the Pleistocene record is comparable to that of the Miocene. We consider that probably the Pleistocene in Mongolia was dominantly a period of erosion.

The origin of a basin, whether as large as Mongolia or as small as a gobi, may be summarized in its simplest terms by figure 153. Section A shows a rugged, mountainous region, and may represent Mongolia as it appeared after each of the great mountain-making revolutions, including the post-Jurassic disturbance. Section B shows the mountains worn down to base-level by long-continued erosion. In Section C, the land has warped, and sediments are being washed down from the uplifted parts into the down-warped areas.

Probably the sediment basins are not of simple origin, but are the resultant of a number of interacting factors:

1. The erosive work of water and wind, which carves out lowlands wherein sediments may be laid down.

2. The agencies which move and deposit the sediments.

3. The supply of sediments available.

4. The slow and intermittent warping of the earth's crust (Figs. 154 and 155). If we suppose that in general the basins form where all the conditions are most favorable (Fig. 155, A-B), the amount of warping that need be assumed would be reduced to a minimum.

Among the most interesting inferences is the shifting of the locus of deposition from place to place (Fig. 156). The Lower Cretaceous Oshih and the Ondai Sair gobi basins are almost certainly connected. Deposition may have begun in the Oshih earlier than in the Ondai Sair, since the Oshih beds are much thicker, and of notably coarser grain than the Ondai Sair beds, and since the paper-shales and large sauropods are found only in the upper beds of the Oshih, whereas they appear in the lower beds of the Ondai Sair. After deposition of the Oshih and Ondai Sair, sedimentation in this region ceased; or, if beds were deposited, they have been removed by erosion. But at Djadokhta, forty miles east of Oshih, a new gobi received at least five hundred feet of fine red sands, probably derived from the destruction of older sediments. At Iren Dabasu, three hundred and eighty miles farther east, the Cretaceous beds rest directly upon pre-Cambrian slates. The locus of deposition shifted, therefore, during Cretaceous time.

At the base of the Altai, referring again to figure 156, the Gashato beds, which are the lowest Eocene strata we have seen, rest on the Djadokhta red sands (Fig. 133, page 316). The gap between the Djadokhta and the Gashato represents an interval of Cretaceous and Paleocene time that has left no sedimentary record, so far as we now know. No younger formation

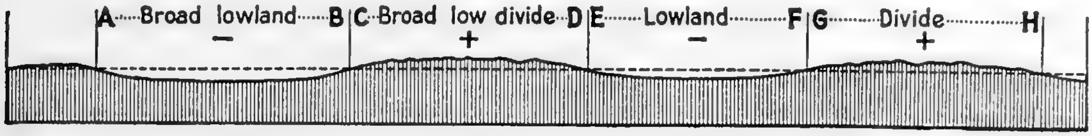


FIGURE 154.—A maturely dissected region of low relief before warping.

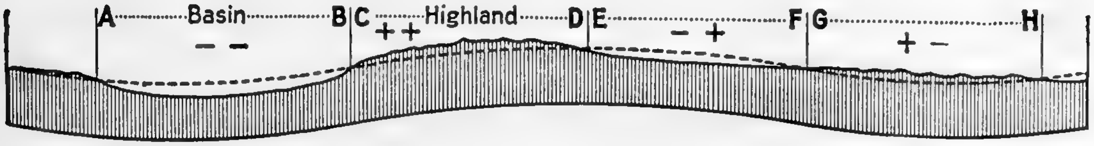


FIGURE 155.—The same region after warping.

Two diagrams to illustrate the relation of warping to topography in the formation of basins, showing how basins may be the result of original relief and deformation combined. Let both higher relief and upward warping be denoted by the plus sign, while lowland and downwarping are denoted by the minus sign. Then, in A–B both relief and movement are negative, so that a basin is formed. In C–D both influences are positive, while in E–F and G–H positive and negative relief and movement are combined, making either basin or highland, according as the relief factor is greater or less than the warping.

was seen in this region, but both to the west and to the east there are later sediments. The Irdin Manha and the Shara Murun formations represent the highest Eocene yet found in Mongolia. Thus there was a shifting of the locus of deposition during the Eocene, from the Altai region in earlier Eocene toward the Iren tala in later Eocene time.

The oldest Oligocene beds yet seen in Mongolia are, apparently, those of Ardyn Obo, which rest directly upon the crystalline oldrock floor. The Oligocene of the Houldjin bench at Iren Dabasu should be rather younger, since it contains *Baluchitherium* bones. The *Baluchitherium* beds of Hsanda Gol are considered Middle Oligocene by W. D. Matthew (1924*b*). Whether or not these formations prove to be of the same age, the evidence of shifting of the locus of deposition is convincing. In at least three widely separated regions, warping recommenced in Lower Oligocene time, so that beds of this age were laid down in one locality upon eroded Lower Cretaceous (Comanchean) beds, in the second upon the bare crystalline rocks, and in the third upon the Eocene Arshanto beds (Fig. 156).

The only Miocene beds yet seen in Mongolia are those of Loh, which rest upon the Hsanda Gol without any notable appearance of a break in sedimentation. Pliocene beds are known from three widely separated localities: the

Hung Kureh, at the foot of Baga Bogdo; the Ertemte, described by Andersson, from a place on the Kalgan-Urga trail about ninety miles northwest of Kalgan, and an unnamed but large gobi, discovered by Teilhard and Licent, near the Tsilin Gol in the southern part of the Dalai tala.

It seems to follow, independently of the inferences just offered, that the weight of the sediment could have had no causal relation to the depression

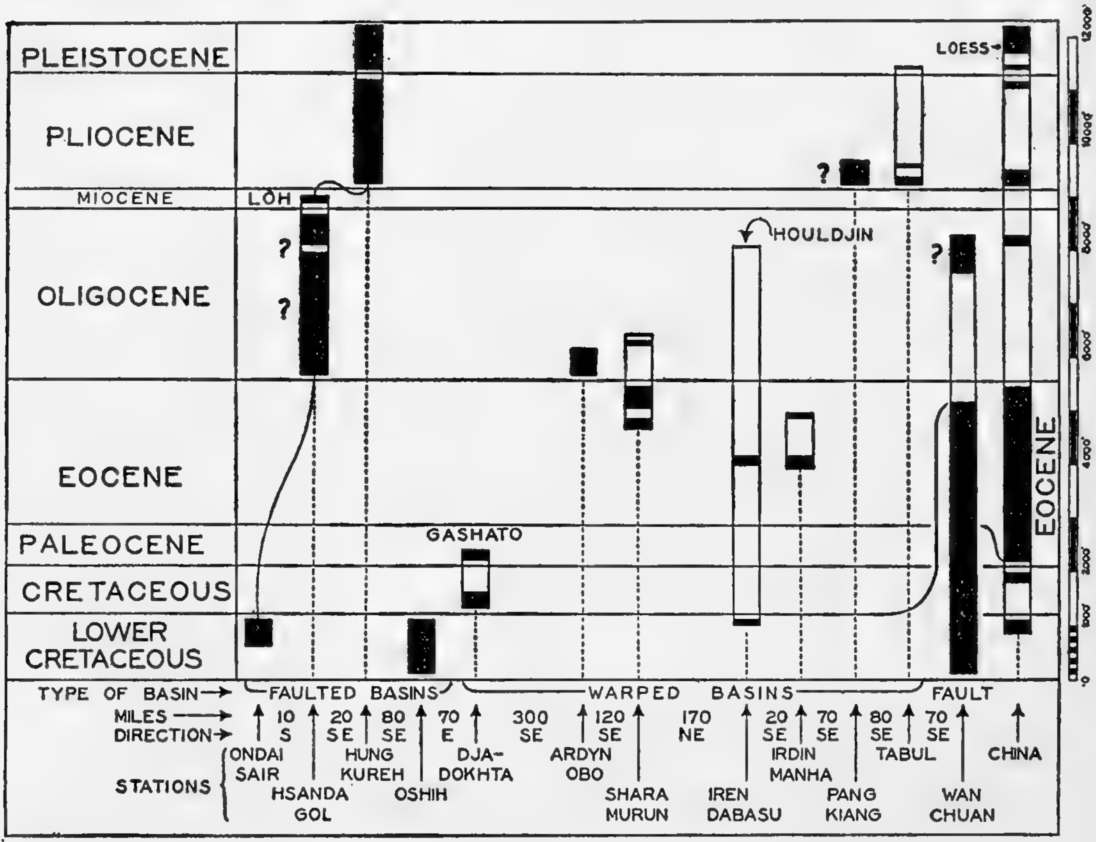


FIGURE 156.—Generalized columnar diagram of the later sediments. Warped basins have been distinguished from faulted basins, the latter carrying by far the thicker deposits. The different basins are arranged in the diagram from west to east. The distances indicated are measured between working stations and camps, and do not measure the limits of the basins. The section for northern China is compiled from J. G. Andersson's "Essays on the Cenozoic of Northern China."

The reconnaissance of 1925 has added a station 40 miles west of Ondai Sair, with 120 feet of early Pleistocene, a post-Pleistocene section at Djadokhta, and a thin Oligocene section at Shara Murun.

of the earth's crust. The fact that areas as large as ten thousand square miles in extent are floored by thin formations, as in the case of the Irdin Manha and Shara Murun basin, seems to indicate that these beds were laid down upon a relatively flat surface that did not tend to sink under the load (Fig. 100, page 199). The crust evidently supported these and other formations while they were peneplaned. The planations are taken to imply great

The stratigraphy of the later sediments is summarized in the accompanying table.

TABLE OF THE LATER SEDIMENTS

Age	Formations	Thickness	Character of Sediments	Typical Fossils
Recent	Playa deposits	1–50	Fine clays and silts	
	Alluvial fans	2000±	Cobbles, gravels, sand, silt	
	Sheet-wash	1–20	Chiefly clay-sand mixtures	
	Drift-sand	1–300	Assorted sand, quartz, feldspar, mica, hornblende	
	Loess	1–10	Fine silty loam	
	Older playa and wind deposits	10–200	Clays, silts and sands	
Pleistocene	"High fans" of the Altai front	1000±	Coarse gravels	
	Gochu formation of deformed fans along the Altai front	1000±	Cobbles and gravels	
Pliocene	Hung Kureh sands and clays	2000±	Finely bedded pond-deposits, windblown sands, and alluvial fan gravels	*Hipparion*
Miocene	Loh	1000?	Olive green and brown sandy clays	*Serridentinus*
	P'ang Kiang?	500±	White and gray sands and silt	
Oligocene	Hsanda Gol	3000	Red sandy clays }	*Baluchitherium*
	Houldjin	15–150	Gravels and yellow sands }	
	Ardyn Obo	500	Gray and red silt; white and yellow sands	*Menodus*
Eocene	Shara Murun	500	Variegated clays and white sands	*Protitanotherium*
	Tukhum	100+	Hard red sandy clays	*Teilhardia*
	Irdin Manha	100	White sands and gray clays	*Eudinoceras*
	Arshanto	100+	Red sandy clays	*Schlosseria*
Paleocene	Gashato	300	Red and brown sandy silts and thin gravels	*Palæostylops*
SLIGHT ANGULAR UNCONFORMITY				
Cretaceous	Djadokhta	500	Fine uniform red sands	*Protoceratops*
Lower Cretaceous	Iren Dabasu	180	Red and gray clays and thin white sandstones	*Iguanodontia*
	Oshih (Ashile)	2000±	Red clays and sands and black paper-shales	*Prodeinodon*
	Ondai Sair	500	White and gray sands and black paper-shales	*Protiguanodon*

GREAT UNCONFORMITY

All rocks below this line are folded.

The Oldrock Floor of the Gobi Region.

Folded and partly metamorphosed sediments, ranging from early pre-Cambrian to Jurassic age, and cut by large and small igneous bodies. (See Figure 130, page 301.)

stability and rigidity of the bedrock floor; that is, the crust neither sank under the load sufficiently to deform the sediments and encourage thicker deposits, nor rose under the negative load, when the region was eroded to a peneplane. We believe isostatic balance can be overset only by very large positive and negative loads, and that the stripping and loading observed in Mongolia have been of an order of magnitude too small to overcome the inertia of the earth's crust, even where fault lines exist. In the dynamics of the region, the sediments played a passive part. Basin-warping and mountain-building were complementary parts of a great orogenic movement or succession of movements, and were controlled, we believe, by deep-seated causes, such as the intrusive movements of large magmas.

CHAPTER XXI

SUCCESSIVE CLIMATES OF MONGOLIA

INTRODUCTION

In our opinion, the case for fluctuating climate in recent time and the far-reaching effect of these changes on the migrating movements both of men and of other animals, are supported by much geologic evidence. It is entirely likely that a peculiarly delicate climatic balance, where even a slight shifting of factors could make decided differences in living conditions, together with a long continental history, have had very far-reaching consequences on the racial history of many forms of animal life. Favorable and unfavorable conditions, by turns inviting conquest or occupation and relentlessly driving out again; nourishing for a time and then ruthlessly applying the chastening hardships of want, trying endurance to the utmost,—these constitute a rough kind of geologic providence whose hand has been felt by every living creature whose life was spent on the open plain. On account of the importance of the whole problem and the broad application that it appears to have, we have undertaken to assemble the evidences in hand which seem to us to bear on climates of the distant past as well as on climatic changes of more recent time.

PAST CLIMATES OF MONGOLIA

We shall not enter into speculations on the climates which may have prevailed in the eras represented by highly metamorphosed gneisses, schists, and crystalline limestones. We shall omit consideration of the Archæan and Huronian eras, and begin with the great graywacke series. We are aware, also, that interpretations of past climates are, at best, tenuous inferences, and that they should be taken cautiously.

LATE PRE-CAMBRIAN OR SINIAN PERIOD

The graywacke series of the Gangin Daba and Khangai Mountains consists essentially of well-bedded, dark sandstones and gray slates, with some conglomerates and a few beds of jasper, but virtually no limestone. The sandstones are composed of bits of slate, phyllite, quartz, and feldspar, volcanic ash, and several types of porphyry. Most of the fragments are fresh and unweathered.

So far as these facts enable us to postulate climatic conditions, we should infer a cool or temperate rather than a tropical climate. Blackwelder (1917) has called attention to the prevalence of dark sediments of the graywacke type in Alaska, and places this same interpretation upon it. Blackwelder reasons that, in a warm and moist climate, the chemical processes of weathering would predominate, and would reduce the country rocks to clay soils or to laterites, which, when washed into their final resting place, would form clay shales. He argues that in a cold climate, on the other hand, the mechanical work of frost and temperature changes and abrasion by wind, water, and ice would predominate among the weathering processes. These agencies tend to break up the country rock into small grains which are but little altered in their chemical composition. In a granite region, arkosic sands made of feldspar, quartz, and mica flakes are formed, while the wash from a region of slates would bring down myriads of particles of scarcely altered slate, which, when mingled with quartz grains and cemented together, make a graywacke. The more finely ground particles, together with some true clays made by chemical weathering, form dark-colored shales. Doubtless a part of the coloration is due to carbonaceous matter derived from plant growth.

The climate of Mongolia could not have been dry, for the sediments are well assorted into distinct, fine clay slates and sandy graywackes, which range from single beds a foot thick to large formations of slate or graywacke many hundreds of feet in thickness. Such widespread masses of sediment could not have been assorted and distributed by any agency other than water. If there were abundant rains when the graywackes and slates were forming, it seems not unlikely that the climate was also cold, for in a warm and moist climate, the minerals bearing iron would be altered to form oxides and carbonates, and the complex silicates would break down to form clay, so that the end product would have been red and brown clays rather than dark graywackes and slates.

PALÆOZOIC ERA

Of the marine Palæozoic formations, only the Permian beds have been studied in any detail. They consist of limestones, sandstones, quartzites, shales, and conglomerates. The gray limestones are composed chiefly of brachiopods and bryozoans, lime-sand, and mud. There are but few corals, and none of the reef-building types. The fauna, therefore, suggests a temperate rather than a tropical climate, though mud and admixture of fresh water may well account for the scarcity of corals.

The clays are thin-bedded and greenish, and may owe their color to chlorite derived from the older phyllites, graywackes, and greenstones underlying the Permian beds. The coarse sandstones include bits of quartz, graywacke, slate, and argillite. Fragments of feldspar and porphyries are present also, suggesting the disintegration of granite and dikes. At least the sandy part of the sediments was derived from several kinds of older rocks which were reduced to small angular fragments without being thoroughly altered by processes of chemical weathering. Either aridity or cold could retard the chemical processes of weathering so that the lands might yield a sediment composed of fairly fresh rock fragments; while a warm and humid country would be apt to send down to the sea maturely weathered rock waste, such as clay. The evidence of the rocks is not conclusive, but it suggests either a cool or an arid climate for the land from which the sediments were derived, and so is not at variance with the faunal evidence.

MESOZOIC ERA

Lower Jurassic Period

The Lower Jurassic rocks of Mongolia consist of conglomerates, sandstones, and shales, with associated lava flows, tuffs, and ash-beds.

The pebbles of the conglomerates are well-rounded and range in size up to boulders a foot thick. They are of many kinds of rocks,—gneisses, granite porphyries, sandstones, quartzites, graywackes, argillites, jasper, and silicified ash, with scattered limestone pebbles. The rounded form suggests mature weathering with enough abrasion to keep the pebble fresh. The presence of pebbles of many different rock types suggests that many formations have contributed to the streams that made the deposit.

The Jurassic pebbles give evidence of having had a complex history. Some are fragments of older conglomerates which were themselves composed of rounded pebbles before the Jurassic period. How many times they have been loosened from a bedrock, worn, weathered, rolled, and again deposited and cemented into a new generation of bedrock it is impossible to say. The important thing is not the number of rock generations that have employed the pebbles, but the fact that they have had a long history.

It seems to us that these considerations lead toward several important inferences:

1. In Lower Jurassic time, relief of the land surfaces must have been great enough to give the streams rather steep gradients so as to move the vast quantities of pebbles which now form the Jurassic conglomerates. Probably the Jurassic deposits were laid out in a series of separate intermontane basins.

2. Weathering and erosion of exposed rock surfaces were continued long enough to change all new rock fragments into well-rounded pebbles with which older pebbles were commingled.

3. Water must have been abundant enough not only to move the pebbles but to wash out the finer sediments and to assort the rivers' load.

Coal is found associated with this series in one place at least in the Gobi region, and remains of woody plants are common, even in the conglomerates. In China and in Siberia, coal in commercial quantities is associated with Lower Jurassic beds. The coals probably represent broad swamps in the old land surface of Jurassic time. Probably the belt of heaviest rainfall lay around the margins of the Gobi region—in Siberia, Manchuria, and China—while the climate in Mongolia was less moist and more variable, as suggested by the abundance of coarse clastics and the paucity of clays and coals. The rocks and obscure plant remains in Mongolia fall in with this interpretation, and indicate a warm climate, with only a moderate rainfall.

Cretaceous period

Oshih and Ondai Sair time.—The thick variable deposits at Oshih (page 270) probably represent a large alluvial fan built during Lower Cretaceous time at the foot of an ancient mountain range. The beds of sand and pebbles represent the zone of active deposition—a zone which shifts from one part of the fan to another with the changing courses of the distributary streams. The fine clays and paper-shales represent the zone of shallow lakes, which is shifted from place to place around the foot of the developing fan. The variations in quality of the Oshih sediments, therefore, probably imply the normal changes in the distribution of coarse and fine material and in the distribution of water supply during the growth of the fan. The variations do not necessarily indicate changes of climate during the deposition of the Oshih sediments.

The dark paper-shales are clearly lake deposits. Those at Oshih and at mile 298 on the Urga trail (page 63) apparently lack fossils and contain gypsum, suggesting that the water was bitter, which would imply the undrained lakes of a semiarid climate.

The abundance of large insects with aquatic larvæ in the Ondai Sair formation suggests that the climate was at least moderately warm. The fauna and flora are so nearly uniform from China to Siberia that we must suppose very similar conditions to have prevailed throughout the region.

Iren Dabasu time.—The red and gray, variable, locally cross-bedded strata of the Iren Dabasu formation (page 203) probably were deposited upon flood plains and in shallow lakes. This inference is supported by the composition of the fauna, which includes a bivalve mollusk, and abundant trachodont dinosaurs, together with crocodilians, turtles, and fishes. On the other hand, the carnivorous dinosaurs and "ostrich" dinosaur are not distinctively water-loving forms.

The small isolated group of lake beds and the fauna suggest an environment, but do not prove a climate. The angular-grained sands containing fresh feldspar, the rapid alternation of clay and sand, the absence of lignite, coal, or dark-colored beds, the lack of plant remains except for a few bits of silicified wood—all suggest a semiarid rather than a humid climate.

Djadokhta time.—The Djadokhta formation is found about forty miles east of the Oshih. It is almost wholly composed of a red sand, so uniformly fine that it will run like sand in an hourglass. Its grains are fairly rounded and polished. Virtually no clay is admixed with the sand, and there are very few beds of clay in the formation. These facts suggest that the sand has been assorted by wind.

Some of the beds are apparently structureless (Plate I) and probably represent settled dust or loess. The zones of small, white, nodular concretions, described in Chapter XX, probably were formed by precipitation in pond bottoms, though it is possible that some of them represent the work of groundwater at the time the sediments were forming. Many strata are cross-bedded, some with foreset beds as much as forty feet long, dipping as steeply as twenty-four degrees (Plate I, and Fig. 152, page 356), others with curved and dissected beds of the type which we commonly ascribe to wind work. All the cross-bedded sands are probably part of dunes. No plant remains and no dark or gray-colored beds have been seen.

The fauna consists entirely of genera which are new to science. Turtle and tortoise bones, which are common in other fossil fields of Mongolia, are rare, and the only other water-loving form is a small crocodilian. All the dinosaurs are small, and all are light-limbed, fleetly-running types, except the *Protoceratops* and an undescribed armored reptile.

Associated bones, even to complete skeletons, are more abundant in the Djadokhta beds than in any others, except perhaps the Shara Murun formation. The ribs of the dinosaurs are expanded, not crushed—a feature which, as Mr. Granger pointed out, suggests that the carcasses were sun-dried and then buried in drift sand. The dinosaur eggs are not broken in fragments but are found whole; they have been somewhat crushed, and in many cases the larger end of the egg is slightly telescoped over the smaller end. Many of the eggs are in their original position in the nest. Washing by water probably would not produce these results, but would displace the eggs and break them up. On the other hand, slowly accumulating wind-blown sand would gradually bury the eggs, crack them and fill them with fine sand. Once filled, they could not be crushed further.

All the evidence,—in the rocks, in the fauna, and in the mode of preservation of the fossils,—seems to point to a semiarid climate. There probably were shallow lakes, withering rivers, belts of sand dunes, and sparse vegetation, including trees along some of the water courses. Nevertheless, this interesting formation and its fauna do not prove that this climate extended over the entire country. The Oshih and Ondai Sair beds denote conditions found over a very large area and therefore give some clue to the climate of the region. But the Djadokhta beds may rather indicate a special and local condition in a region that as a whole was more moist. Until more deposits are found and correlated with it, we cannot say with confidence that these conditions were widespread.

On the whole, the evidence suggests that Mongolia in Cretaceous time was semiarid yet somewhat rainier than the Tertiary, as will be brought out more clearly in the pages that follow.

CENOZOIC ERA

There is abundant evidence that during the Cretaceous period Asia was already a vast continent with large inland basins and that this condition continued into the Cenozoic era. It has been considered that the great central area in Asia may have played an important part in the evolution and distribution of mammalian faunas, including man. The Tertiary climates of Asia, therefore, are of especial interest.

In the Himalayan Sea, south of the great Cretaceous continent of Asia, there were stirrings of uprising land masses even in the Eocene, although limestones with nummulites were still forming in northwestern India. Some time afterward, that seaway was drained, and the Himalaya ranges were folded and uplifted, welding the southern lands of India and Arabia to the northern continent. Probably this greatest of mountain-making revolutions occupied the whole of Tertiary time. It is very probable that the uprising of the ranges was slow and that it took place in a series of minor movements. All the successive phases of this complex history of uplift, erosion, and renewed uplift must have had far-reaching effects upon the climate of the lands around, but especially in the regions north of the Himalayas.

The same era witnessed the building of the arc-shaped ranges that fringe the eastern coast of Asia, as well as the uprising fault-block mountains of the interior. Beside the mountain-building, a general continental uplift must have been in progress, and broad areas were warping into high inland basins. There is evidence which suggests that, though there have been many changes of climate, the range of variation has been small. No evidence of very heavy rainfall has been found in the entire record of the Tertiary, and the climate seems to have varied between semiarid and desert conditions during the entire era.

Eocene period

Gashato time.—The Gashato beds have been described on page 358. The clays, sands, and gravels are poorly assorted; the coarser grains are commingled with the finer, and all beds, even the gravels, carry some clay. These facts suggest rapid accumulation by streams that were not sufficiently permanent to assort their load. The abundance of gypsum in some of the clay beds suggests the concentration of salts in enclosed waters. There is no coal or peat, or any plant remains other than a few fragments of silicified wood, though the gray and brown beds probably carry a little admixed carbon. Probably there were no large swamps, and the vegetation was sparse. The fauna includes turtles and a few aberrant mammals, most of which were adapted for herbivorous feeding, though some were insect-eaters. The fauna gives little clew to the climate, but it could well have been adapted to a treeless prairie or a semidesert. These meager data indicate a climate that was not markedly wet, though water played the dominating rôle in the deposition of the sediments.

Arshanto time.—Part of the Arshanto beds are structureless red clay which resembles loess except that it lacks the characteristic vertical cleavage. True loess is formed by the settling of dust from the air, or by the action of rain, which washes the dust out of the air. There must be enough vegetation to entrap and hold the dust, so that the winds that brought it cannot carry it away again. The well-bedded, greenish fissile shales, which outcrop in the Iren Dabasu hollow are undoubtedly the filling of a shallow lake. The lens of greenish sandstone in which skeletons of small lophiodonts were found is a stream channel filling. The Arshanto suggests an open grass country with semiarid climate, rather than a desert.

Irdin Manha time.—The Irdin Manha beds (page 207) consist almost wholly of the deposits laid by streams. The inference that the streams were evanescent, but ran vigorously when there was a supply of water, is supported by the following facts: (1) The sediments are not well assorted, but consist of commingled pebbles, sand, and fine dust; (2) many strata are cross-bedded; (3) many of them are channel fillings, and cut one another in a complex way. The presence of highly polished pebbles in great number suggests effective windblast.

The fauna (page 208) includes ranging animals adapted to the open plains; but tortoise and turtle bones are abundant, as well as a few fish vertebræ. There were, therefore, some aquatic forms as well. Fragments of silicified wood are not uncommon, but still there are no dark-colored beds, and no lignite or coal.

It is probable that the Irdin Manha formation represents a rather dry flood plain or alluvial fan, with trees or patches of wood along the courses of intermittent, shifting streams. Such a deposit suggests a semiarid climate.

Shara Murun time.—At Shara Murun the chief sediment is varicolored clay, capped by light gray sandstones. We judged the clays to be deposits made in shallow lakes, as they are well bedded and contain abundant gypsum. No fossils were found in the gypsum-bearing beds, but where the gypsum is absent, great quantities of bones and several nearly perfect skeletons were found in small areas or pockets. Probably there were fresh-water springs or water holes that made these spots at once a gathering ground and a cemetery for the inhabitants of the country in Eocene time. The fauna includes ranging types resembling those of Irdin Manha in their adaptations. All these facts suggest a semiarid climate with inland drainage and drying lakes in which gypsum was precipitated.

Oligocene period

Ardyn Obo time.—The Ardyn Obo formation (page 174) includes green and red sandy clays, in the lower part of the section, while the upper part consists almost wholly of sand and gravel. The cross-bedding of all the sands and gravels dips at low angles of fifteen degrees or less. Vast numbers of channel fillings, intricately crossing and cutting one another, contain a mixture of large and small pebbles and grains. No associated skeletons, but only scattered bones and skulls were found. Many of the fossils were discovered in the bottoms of the channels, suggesting that they were washed down by the streams of Lower Oligocene time.

The fauna includes a slender-jawed carnivore with much the same general build as a fox; two rhinocerotids, one of which was probably semiaquatic; at least three artiodactyls, and fairly abundant tortoises. The physical and faunal evidence suggests flood plains or alluvial fans with water at least as abundant as in the Eocene. We again note the absence of forest-living forms, and of plant remains or carbonaceous beds, although some of the strata have a grayish color. We judge that the climate was semiarid.

Houldjin time.—The Houldjin gravels (page 205) are much like the upper gravels at Ardyn Obo—yellow gravels and sand, well washed. They contain teeth and worn fragments of the bones of ranging animals, but no associated skeletons have been found. Probably, like the Ardyn Obo, the Houldjin beds were laid out on a broad flood plain or fan under semiarid conditions.

Hsanda Gol time.—The Hsanda Gol formation (page 233) begins with a heavy conglomerate, locally three hundred feet thick. It passes upward into red sands and clays, which are thick-bedded, lens-shaped, uniform deposits, and no bed or unit can be traced for more than a half mile. Such deposits might be formed along the foot of a large alluvial fan, where there were broad, shallow, playa basins that filled when water was abundant. It is possible that some of the thick, structureless beds are dust deposits rather than lake fillings.

The fauna includes a group of ranging, browsing animals, one of which is the giant *Baluchitherium*, which was found also in the Houldjin gravels; a number of insectivores, most of which resemble the shrews and moles, but one of which may have been arboreal; and a great host of burrowing rodents of which eleven species have been named. This assembly, according to W. D. Matthew (1924 *b*), has the aspect of a desert fauna, or at least a fauna adapted to an open plains country. Most of the beds bear no plant remains, though a few fragments of silicified wood are found, and the chocolate brown and gray beds contain a little carbon.

The Ardyn Obo, Houldjin, and Hsanda Gol formations were probably deposited chiefly by running water. In all three, the sediments and faunas offer evidence that suggests vigorous temporary streams and vanishing lakes, rather than permanently well-watered conditions. We may picture, under a temperate, semiarid climate, a land of open plains with long, low aprons of alluvium stretching down from low ranges of oldrock hills; dry stream courses with patches of trees along their banks, and shallow, often drying lakes in the bottoms of broad depressions.

Miocene period

The only Miocene beds thus far found in Mongolia or in China are the gray, brown, and olive-colored clays at Loh (page 365). If Mongolia were an inland basin in Miocene time, it is hard to see why deposits of that age were not formed, and we may hope to find them in future explorations. If, on the other hand, the entire region was being eroded, it is possible that the exportation of material exceeded the deposition, and that almost no Miocene deposits were formed. In any case, the lack of adequate stratigraphic data makes Miocene history one of the large unsolved problems of Central Asia.

Pliocene period

Hung Kureh time.—The Hung Kureh beds (page 365) include fine white and yellow or buff sands, and light gray well-bedded clays. The sands have yielded the bones of deer, Mastodon, Hipparion, and a large ostrich, while the bedded clays contain small gastropods and plant remains. The deer might be a forest animal, but the horse and ostrich were both adapted to open plains. The clays are clearly pond deposits, but at least part of the sands are probably wind-blown. It is difficult to estimate the climate, but it must have been more humid than the earlier Tertiary climates.

Ertemte time.—Dr. J. G. Andersson (1923, *a*, page 40) has described a deposit of clay and sand at Ertemte, near Hallong Ossu in southern Mongolia (Fig. 7, page 51), which he believes to be an old lake bed. He obtained fresh-water mollusks, some small fish bones, and many rodents including a beaver, as well as teeth of deer and rhinoceros, and an egg of the extinct ostrich, *Struthiolithus*. On the whole, this is a water-loving, forest-dwelling fauna, although the ostrich and rhinoceros are typical creatures of the open plains. It needs, as we have seen in Mongolia, only a small patch of trees to contain an isolated woodland fauna.

In an unnamed basin, south of the Tsilin River, in southeastern Mongolia, the two distinguished French scientists, Père Teilhard de Chardin and Père Emil Licent (1924, *c*), found a Pliocene fauna with remains of Giraffidæ, a rhinocerotid, a horse, a mastodon, a hare, several mustelids, and an ostrich. This is a typical plains fauna, and is found in "red beds." Above the red beds are white sands and marls, with turtles, mastodon, a horse, a badger, a beaver, smaller rodents, mustelids, and large deer. Père Teilhard correlated the higher beds with those found by Andersson at Ertemte (personal communication). The beaver and deer again suggest a forest environment, although this need not be implied for the whole country, especially as most of the other animals were rovers of the plain. The deposits themselves are simply described as "terre rouge" and "marnes et sables blancs," but at least no carbonaceous beds or plant remains were noted.

It seems not improbable that the Pliocene was rather moister than the present, and that lakes existed and patches of trees maintained themselves in places that are now desert.

Pleistocene period

The Pleistocene had the most variable climate of any post-Cretaceous period, including epochs warmer than the present and epochs in which the higher mountains bore large alpine glaciers, while portions of the Siberian coastal slopes were covered by broad ice caps. The Gobi region was not glaciated, but its geologic processes were affected by the climatic revolutions of that time.

In the excellent little book on the *Evolution of Climate*, C. E. P. Brooks (1922) reviews the evidence on the glaciation of Asia. Only two glacial epochs seem to be demonstrated for northern Asia. The earlier glaciation was the more severe, and ice sheets formed in the extreme north (Fig. 157). The later glaciation was confined to the mountains. Brooks (1922, page 82) believes that the first advance is "contemporaneous with the first glaciation (Günz) of Europe," while the second coincides with the third, or Riss, of Europe. For the Himalaya and Tien Shan, three to five ice advances have been recorded by Oldham (cited by Brooks, page 82) and Huntington (1905, *a*, page 186). Epochs of glacial advance seem to have been marked by moister

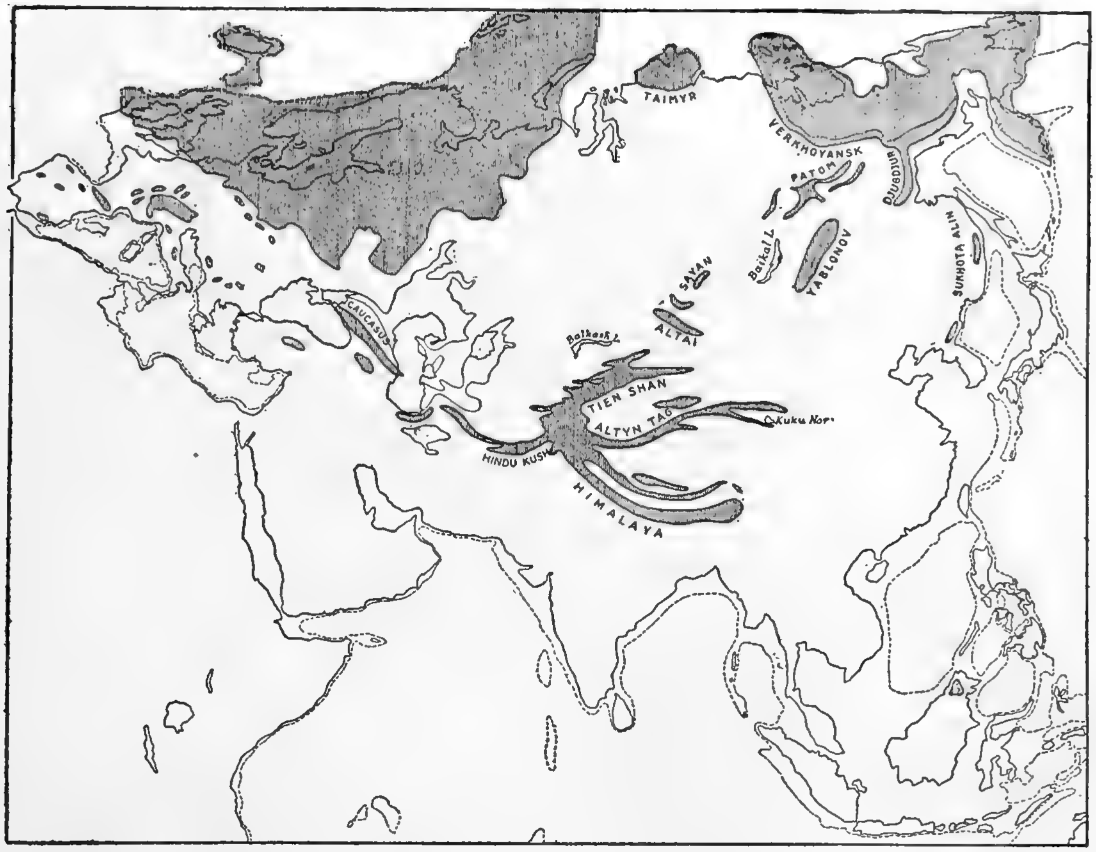


FIGURE 157.—Glacial map of Eurasia. The shaded areas show the maximum known extent of glacial ice during the Pleistocene. All those south of the Verkhoyansk Mountains were of alpine type. The striking feature is the small extent of glaciation on the continent of Asia. A light line shows the probable maximum extent of the Caspian Sea. A dotted line represents the present 49-fathom submarine contour showing the possible land connections of that time during epoch of uplift.

climates, with increased stream erosion and increase in the size and number of lakes.

We observed in the Gangin Daba Mountains, at altitudes between 6,000 and 7,000 feet, that many valleys start in bowl-shaped heads (Fig. 158 and Figs. 29 and 30, pages 83, 86). They are weathered and rounded, and no moraines are connected with them. In one of the bowls the stream cuts a slight trench through the rock at the entrance, which suggests that the floor of the bowl was somewhat excavated by ice that once occupied it. If they are cirques, they represent only an incipient glaciation. Streams are dissecting them and changing their original form. Their worn and weathered condition suggests that they belong to an early epoch of glaciation.

At our camp in the Khangai Mountains, some ten miles south of the Arctic divide, and at an altitude of about 8,000 feet, the valleys are flat-floored, steep-sided, and head in broad hollows that may have been cirques. No

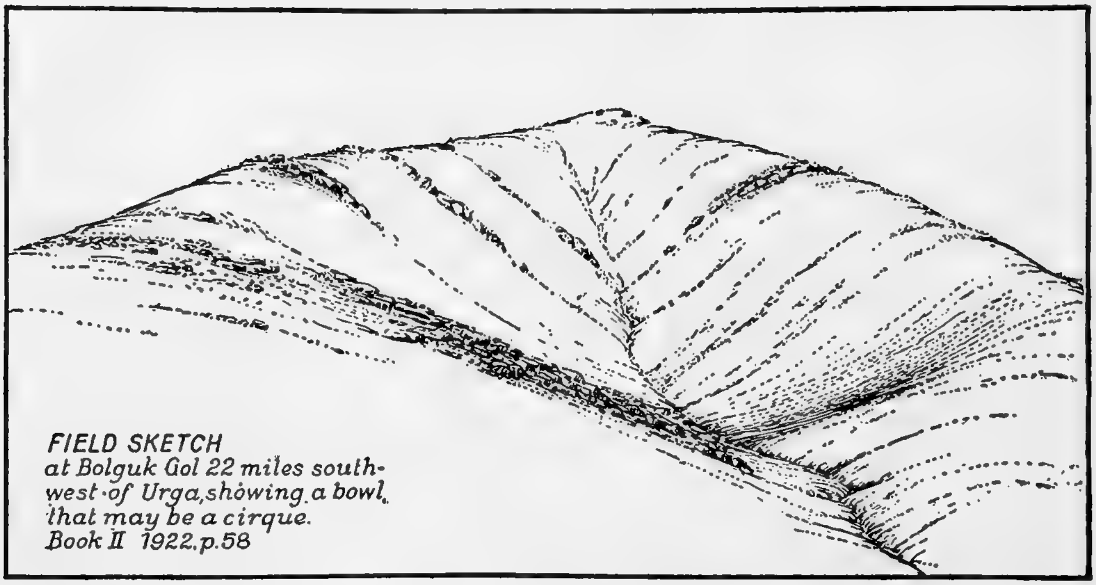


FIGURE 158.—A bowl-shaped valley head. Field sketch in the steeply upturned graywackes of the Gangin-Daba Mountains.

moraines were seen, though large beds of washed cobbles were found on the flat floors. If, as we suppose, the valleys were glaciated in an early epoch, the effects of ice action have been largely cleared away.

Looking northward from our camp, we saw at the Arctic divide undoubted cirques with sheer, precipitous walls (Plate XIV, page 130, and Fig. 149, pages 344–345). We estimate that the mountains in which they were carved stood about 10,000 feet above sea level. They are young cirques, separated by broad areas of smooth, unglaciated upland. Although we had no opportunity to visit and examine these glacial bowls, we infer that they were made in the last glacial advance. It seems probable that alpine glaciers formed in this region in two distinct epochs, separated by a long interglacial period. If the inferences drawn from the obscure cirque forms are correct, the earlier glaciation was much the more severe and affected valleys two thousand to three thousand feet lower than did the glaciers of the later epoch.

In the Altai, we saw no undoubted cirques except the distant view of those in Ikhe Bogdo. The deep narrow valleys of the ranges visited by us have the V-shaped cross-section characteristic of stream work. Except for the record of the cirques, the Ice Age in Mongolia is the most difficult period to read, because of the lack of recognizable deposits. In northern and central Mongolia no undoubted Pleistocene fossils were found in either 1922 or 1923, and the only evidence that suggested Pleistocene age is the abundance of coarse rubble in the ridges between Hung Kureh and the Baga Bogdo front (Plate XXX, in pocket). In 1925, Pleistocene deposits were found at Hung Kureh at the north base of Baga Bogdo in the Tsagan Nor basin, and at Lake Kholobolchi, forty miles west of Tsagan Nor. They will be discussed in a later volume. Andersson reports, in southern Mongolia, deposits of fine sand in which bones of an elephant and a rhinoceros were found (1923, *a*, page 45).

That peculiarly characteristic Pleistocene deposit called loess seems to be lacking in Mongolia. In our explorations we saw little or none, and we find no reports of it in the literature except from the extreme southern margin of the Gobi. The loess of China, south of the Gobi, may well have been blown from Mongolia and from the basin of Lop Nor, especially if the mountain barriers that now separate these lands from China were lower during part of Pleistocene time than they are now. Deposition of loess probably implies at least a moderate rainfall in the area of accumulation, for the rain washes down the dust that the wind has carried, and there must be vegetation to hold it and prevent the wind from taking it up again. But the basin from which the dust is carried must be one in which fresh exposures of fine sediment are offered to the wind. Drying lakes, the outwash of withering rivers, or fresh deflation hollows in fine sediments offer favorable supplies of dust and sand to the winds. These considerations suggest that during part of the Pleistocene, while the loess was forming in China, Mongolia was being actively eroded, and that large amounts of material were being exported from Mongolia by winds. Whether the rivers had a better connection with the ocean than they have at present is not known, but certainly one of the chief problems of the physiography of Mongolia is the enormous amount of material that has been removed from the country in geologically recent times.

The map (Fig. 157), assembles the known evidence for maximum glaciation of Asia; the contrast with the vast ice sheets of Europe and North America is salient. Apparently Asia as a whole was markedly drier than Europe or North America during the entire Pleistocene; for, whereas these other continents had at least four major glaciations, Asia had but two, corresponding rudely with the first and third glacial epochs of Europe. Even granting this, however, Asia was probably lower, warmer, and rainier during much of the Pleistocene than at present; and that period witnessed the growth of mountains and several adjustments of continental level, besides great changes in climate.

RECENT CHANGES OF CLIMATE

The retreating glaciers between the Pleistocene and the present, throughout most of Asia, were not large enough to have such profound effects upon the climate as they had in Europe and North America. For this interval we find many evidences of climatic changes: in the building and partial destruction of several successive alluvial fans along the Altai front; in the ancient beaches at Tsagan Nor; in the redissection of the gently sloping walls of hollows (Fig. 143, page 339); in the renewed dissection of smooth surfaces which formerly supported a richer carpet of vegetation than at present; in renewed dissection of the Gobi erosion plane; in the carving of broad valleys by streams which have vanished, and whose channels are now filled with wind-blown sand; in the failure of rivers to reach their terminal lakes; in the shrinking of the size of meander-curves of rivers, as shown by the large abandoned meander-scarps; in the drying of salt lakes to form salt pans; in old drawings cut upon rocks by a vanished race, picturing animals that lived in woodlands, though the region is now bare of trees. It is not yet possible to correlate and date these changes, but they imply many alternations of climate, with a steady swing toward a drier climate in the present day. The nature of the evidence is discussed at greater length under the following individual heads.

EVIDENCE BEARING ON CLIMATIC CHANGE

Dominant denudation

None of the streams of the central Gobi flows out of it to any other region. Numerous streams from the north flow from the Khangai Mountain country, across hard and soft rocks alike, into basins within the Gobi. Their sediments are deposited either along their present courses or in lake basins at the end of the system. In spite of this fact, which would lead one to expect extensive recent accumulations, there is surprisingly little new deposit to be seen. The land forms of the present surface are almost wholly the result of erosion. Most of the erosion is plainly the effect of running water, though there are abundant evidences of wind-erosion in rocks of many kinds. It is clear, therefore, that there is greater total erosion than total deposition, and that the present is a destructional epoch, in striking contrast to certain earlier periods. The only explanation which appears to meet all the conditions is a change of climate toward greater aridity. Probably this is only one of many alternations of climate, which extend back throughout the history of the continent, and which may account for some of the gaps and changes in the sedimentary record.

Double dissection

In the open ground of the Wan Ch'uan Hsien Pass, above the porphyry gorge (Fig. 5, page 47), a remarkable double erosion-form is presented by the marginal slopes of the valley. There are clearly two stages of erosion,—one comparatively ancient, the other new and active. Smoothly rounded, gently sloping forms of rolling country are cut sharply by vigorous new gullies, making a most complicated and intricate picture (Plate XLI, A). There is no doubt that the older form represents a control of some sort, strikingly different from that of the present epoch. Formerly there was a tendency to develop simple, smooth outlines, as though the land were protected from vigorous destructive erosion. More recently, these protective controls have failed, and at the present time a vigorous dissection is in progress and has been operating long enough to partly destroy the older topography.

It is commonly suggested that deforestation is responsible for removing the original protection, but we believe that artificial deforestation has been an incident rather than a large factor. At the present time, seedlings do not catch and grow on this ground; the only trees are along the stream in the bottom of the valley. If artificial deforestation had been the cause of the change, it would not prevent the growth of new seedlings on the unoccupied ground. The fact that they do not catch suggests that the real controlling conditions are climatic, and that the present cycle is one favoring vigorous dissection because of its greater aridity and the consequent failure to support a protective cover of grass. Therefore, the double dissection pattern of Wan Ch'uan Hsien Pass is direct evidence of a change in climate toward increased aridity.

The choked gorge of Wan Ch'uan Hsien Pass

Below the redissected sedimentary ground which has just been described, the stream runs through a short, deep, narrow notch with almost vertical walls, which has been cut across a range of tilted porphyries (Plate XLI, B). If the river were in full eroding operation at the present time, the rock gorge would be virtually bare, with a floor of solid rock. But if the stream has been reduced in volume, and is overloaded with sediments washed from the sharp, new gullies just described, it would pile along its valley floor the burden that proved too great to carry, and so would choke the narrow gorge with gravels. This is exactly the present condition. The pass is clogged with gravel, and the stream is not actively cutting on the rock bottom (Plate XLI, B). There must have been a time when the stream was vigorous enough to cut out the notch that is now partially filled, and that time represents an epoch of greater humidity. Wan Ch'uan Hsien Pass, therefore, in its choked condition, is an evidence of change of climate toward more arid conditions than formerly prevailed.

Desert trees

Trees of any kind are rare in the desert region of Mongolia, but isolated trees, and even rows of large elms, are seen at a few places along the margins of dry stream courses. The mere fact that mature trees, gnarled and battered, exist there unaccompanied by saplings, points to a time more favorable than the present for the germination of seeds and the success of new tree growth.

The forest margin

It was the good fortune of the Expedition to spend several days at Sain Noin, on the very margin of the northern forests, where groves of trees occupy the northern slopes of the ridges.

Here along the picket line between the forest and the desert or non-forested region, the evidence of fluctuating climate, changing from favorable conditions to those unfavorable for the lodgment and growth of trees, is quite plain. In a grove covering a stretch of half a mile, the trees are prevailingly of two sizes. There is a growth of old trees, averaging two hundred and fifty to three hundred years in age, which forms the chief stand and covers the maximum area of ground. In addition, and in contrast to the old trees, there is a rather dense growth of young saplings, with only a few members of intermediate sizes. There is no regular gradational series of younger trees of various ages. It is very striking that there are just two dominant sizes,—a large size represented by the old trees, and a small size represented by the younger ones.

In the absence of artificial means of control, such as deforestation, which is not practised by the Mongol people, there appears to be only one good explanation. Evidently in an epoch, two hundred and fifty to three hundred years ago, the climatic conditions were such that the forest was able to advance by the catching of seeds on this hillside, until a grove was started that is now represented by the old trees. Subsequently, for a long time, conditions were not so favorable, and, although a few trees were started in the more protected central portions of the grove, the outer margins were wholly unoccupied by any new growth until comparatively recent time, when conditions again became favorable for young trees to take root in great numbers. Some of these are seventy-five years old; much the greater number are younger,—twenty-five to fifty years old. Apparently the present is again not quite so favorable for seedlings.

Only one small grove had lodged beyond this picket line—a group of a dozen or more trees on the next hill to the south. That grove marked the extreme encroachment of the forest in the most favorable epoch of recent time. There are no representatives of the second or latest favorable epoch; in other words, there are no saplings, but instead only old, wind-battered trees, isolated as if abandoned to their fate by the retreat of the forces that set them out, and not reached by the last rally in their behalf fifty years ago.

It appears, therefore, that the earlier epoch, centering about the time

PLATE XL.

A. AN OUTPOST FOREST AT THE ARCTIC DIVIDE.

The larger trees represent a successful early invasion of the Siberian forest into the edge of the Mongolian basin. The smaller growth represents a later invasion, after an interval of unfavorable climatic conditions.

B. TERRACES IN THE LATEST ALLUVIAL FAN OF TIGER CANYON AT THE FOOT OF BAGA BOGDO.

PLATE XLI.

A. TWO STAGES OF DISSECTION AT WAN CH'UAN.

The gullied valley side at Wan Ch'uan, showing an older smooth surface which is being actively redissected. The oversupply of waste thus furnished is filling the valley bottom.

B. THE CHOKED GORGE AT WAN CH'UAN PASS.

The rock gorge is much deeper than the present profile which represents an excessive filling of the valley with waste.

three hundred years ago, was a more favorable climatic epoch than the last one, centering about the time fifty years ago. In any case, the evidence seems to support the hypothesis that the climate of Mongolia fluctuates between changes from more arid to less arid conditions, in cycles of some kind, with intervals measured in only a few hundred years.

These observations were checked up by counting the rings of trees that were available in the vicinity of our camp. The forests are wholly of larch (tamarack), which apparently is one of the most hardy trees under these trying conditions, and thus serves as an advance guard for the forests of the north in their contests with the forces of the interior deserts.

Tree growth at Tiger Canyon

Under a different head, attention has been called to the fact that the original maximum development of the modern alluvial fan at the mouth of Tiger Canyon has been trenched by stream action, with the development of two or three pronounced terraces (page 312). The trench at the apex of the fan is at least a hundred feet deep. The water, issuing from the canyon, sinks completely out of sight in the first few hundred feet after reaching the alluvial fan material; but far out along the distributary channels, which bear evidence of carrying water at certain seasons, there are poplar trees of a species resembling cottonwood. They are fairly numerous for the first part of the stretch, but gradually become scattered and more widely spaced, until at the distance of a mile, there remain only a few rugged, gnarled sentinels. The point of special interest is that nearly all of this tree growth is mature; among the more distant groups there are no young trees or saplings. Almost all the trees represent a former condition which must have been much more favorable than the present to the establishment of young tree growth.

This single generation of trees must indicate a marked change of conditions. A lessening of moisture is the only change that seems most likely, as the rock floor has not altered, and there is no possibility of the soil having behaved very differently one time from another. It is, however, entirely possible that there were times of greater rainfall, so that abundant water could be carried to greater distance beyond the mouth of the canyon, making the distributary courses favorable to the establishment of young trees. The lack of saplings indicates that the present is a period of comparative aridity, perhaps not by any means the driest interval experienced by the region, but still sufficiently arid to produce conditions less favorable than those at the time when the groves of trees were first established. Only the most vigorous of the old stock have maintained themselves to the present time, and evidence of their coming annihilation is apparent in the fallen trunks that lie half buried in the shifting gravels.

The trees that grow along the distributaries from Tiger Canyon, therefore, seem to have the same significance as is gathered from features of very different sort in other places. At several other localities with slightly different physical surroundings, we noted the same phenomenon of mature trees which have all the appearance of being the last remnants of more vigorous colonies. Some of these are far out on the open plain along dry stream courses, and occasionally one sees two or three lone trees, clinging to the side of a hill or at the outlet of a ravine. The evidence presented by desert trees from many localities favors a climatic change, in comparatively recent times, great enough to register its effects in numerous ways.

Ancient stream courses

In many places in the Gobi region there are typical valley forms in which there is no water. It is quite beyond reason to believe that these could be made without the work of running water, and yet, under present climatic conditions, it is impossible that any such forms could be produced. It seems to us that the facts point to the conclusion that in comparatively recent time more humid climatic conditions prevailed, with rainfall sufficient to develop streams of running water in valleys that are now dry. At that time, the larger erosion effects were produced,—effects that are much greater than could result under the present régime. In the same category should be placed the evidence offered by "misfit" streams; for the meanders of all the larger rivers are of much smaller curvature than the concave scarps left by the meanders of a former epoch, and therefore indicate a shrinking of the rivers in comparatively recent time.

Terraced alluvial fans

A magnificent series of modern alluvial fans borders Baga Bogdo on the north side. The streams that have dissected this recently uplifted mountain block have deposited the large fans that reach out for several miles beyond its base and form a striking physiographic feature. They are developed at certain places on such a scale as almost to bury the bordering hills of a previous cycle of erosion; but the feature of immediate importance in this connection is their own dissected condition.

At the mouth of Tiger Canyon, for example, the last alluvial fan, in its maximum development, reached into the mouth of the canyon more than a hundred feet above the present level of the stream. This fan has been trenched by the same stream which originally made it, and has not only developed a miniature canyon in the fan itself, but has marked its stages by several terraces. Whatever the causes may be, the later tendency was to erode the fan already built and to redistribute the material.

This same general effect is apparent in each of the fans throughout the length of the Baga Bogdo block, and is apparently quite independent of the rock composition of the block from which the material has been derived. Furthermore, there is in sight no evidence of renewed uplift or of dynamic disturbance of any corresponding sort since the time of maximum development of the fan itself.

We judge, therefore, that the chief cause of the shift of processes, from deposition to marked erosion, is climatic change. The present is an epoch of greater or of less aridity. It is a fair question whether greater aridity with less water in the stream would tend to build up or to destroy the deposits already made. Our judgment, in this case, is that less water would build up and more water would erode the fan. The terraces apparently indicate a more balanced condition than is represented by either the building or the dissecting processes.

Quite aside from the problem of whether dissection would be aided by more arid or by more humid conditions, it is evident that, in either case, climatic change seems to be supported by this feature. There have been times which facilitated the accumulation of such deposits, and times subsequent to these when the fans were destroyed; these two very different kinds of epochs are distinguishable from a third, in which the balance of opposing processes is much more nearly reached. Such evidence as there is in the alluvial fans points to recurrence of climatic change.

Minor scarps in erosion hollows

Intimately associated with climatic changes are the "false cuestas," described in Chapter XIX in connection with the origin of desert hollows. The "cuestas" are clearly remnants of the once smooth and gentle slope from the edge of the Gobi upland to the floor of the hollow (Fig. 143, page 339). At one time there must have been sufficient protection of vegetation on the smooth slopes to prevent active gullying. When the change to greater aridity weakened or destroyed the protecting vegetation, the rainwash dissected the steeper parts of the slopes, but was too scanty to destroy the gentler slopes below, where decrease of gradient lessened the erosive power of the water. These gullied bluffs and their fringes of minor scarps are found especially along projecting headlands of the walls bordering the larger hollows (Fig. 146, page 340). Therefore, they are where the soil dries most readily, and where a lessening of the rainfall would first affect the protecting vegetation.

Lakes

In many of the enclosed hollows, for which wind erosion is the only tenable explanation, there is at the present time standing water, which forms small lakes, saltpans, or swamps. At most places, the waters are doubtless shallow, but in others there is considerable water. This condition exists both in the sedimentary and in the granite areas.

The standing water in these holes prevents all wind attack, and it is evident that the bottoms could never have been scooped out under the present conditions. The only logical conclusion is that they must have been made under an earlier climatic condition of greater aridity, with a consequent lower water-table or less precipitation, when the floors of the hollows were dry.

It is possible that in a still earlier cycle the climate was moister than at present; in that case, there should still be traces of former strand lines and greater depth, or evidence of the former presence of water where none is now. In the hollows occupied by larger lakes, such as Tsagan Nor (Chapter XIII), where the conditions were more critical and more nicely balanced, a history of climatic change is legible.

Ancient lake beaches of Tsagan Nor

Tsagan Nor, just north of the Baga Bogdo range, is the largest desert lake yet visited by the Expedition. The floor is so gently sloping that one can readily wade out into the water several hundred paces. The lake is exceedingly shallow,—probably nowhere over ten feet deep,—but it covers an area of nearly six square miles. It is slightly salt, but not too salt for use by the camel train and horses.

Special interest attaches to the strongly marked, abandoned beaches along the northern shore, which indicate a succession of much higher water levels in former times (Plate XLII, B). If the lake were filled to the height indicated by the upper beaches, it would overflow at the east end and establish a stream which would follow a general easterly course, marked out by a broad valley in that direction, which doubtless was at one time the lake's outlet.

The reason for emphasizing this point, however, is its bearing on changed climatic conditions. At the present time, and apparently for a long while in the past, there has not been enough water furnished to the Tsagan Nor basin to maintain a level of the lake high enough to overflow. In order to make the beach terraces, there must have been a time when water supply was more plentiful than now. This could happen only with a change toward greater humidity. Each of the well-marked beach-levels must have been maintained for a long time. The changes that have taken place, therefore, have not been gradual or continuous, but they have come by steps or in cycles.

It is possible that there has been a time of greater aridity than the present, and the very existence of the lake basin is somewhat of a support to that hypothesis; for its broad, shallow, and rather oval form is not that of a river valley, but more that of a shallow deflation hollow. Probably it is indeed a deflation hollow, whose floor must have been dry when the winds were excavating it, and therefore the form of the basin of the present lake indicates a preceding arid cycle.

This explanation would agree closely with observations made in the granite areas farther to the north and northeast, which have already been described (page 116) and interpreted as indications of a former stage of greater aridity than the present. It would agree, also, with the evidence of the trenched and terraced alluvial fans of Baga Bogdo.

Additional observations made in 1925 fully substantiate the inference that the lake has been dry before. This evidence and argument will be presented in a later volume.

Glaciation

The entire failure of general glaciation and the restriction of glacial ice to the high mountains, indicate a comparatively arid climate during the Ice Age, or, at least, a distribution of seasonal precipitation which proved unfavorable for the continuous development of ice and snow. It would be possible to have heavy rains, chiefly in the summer time, and a lighter precipitation in winter, and yet wholly escape the development of notable glaciers. Inadequate or badly distributed seasonal precipitation would accomplish the same result. Observations made in 1925 throw a flood of light on the problem of climate in Pleistocene and Recent times, but this material cannot be made available for this volume.

A vanished race

Near the easterly terminus of the great Altai Mountain ranges, in the vicinity of Artsa Bogdo, where an old basalt lava flow has been undercut by erosion so that large, flat-faced blocks lie about, we found drawings incised on some of the rocks. They are unlike anything that the Mongols do, and the subjects are in part different from those available in the desert of to-day. In the illustration here used (Fig. 159), the unknown artist has represented a reindeer or an elk, and possibly a moose, and a man with bow and arrow. None of these animals inhabits the region now, and both the animals and the men belong to a country with a different climate. The inference is that when the drawings were made the mid-Gobi region, at least in the vicinity of the easterly ranges of the Altai, had a climate favorable to these animals. It must have been wooded in part, with more water. Both the unknown race of hunters and the animals that they chased have moved on. Presumably the climate changed toward greater aridity, and the land no longer supported them.

We do not know exactly when this happened; doubtless it was very long ago. Probably the drawings are prehistoric—made by a people who wrote in pictures and lived by the chase. The drawings emphasize, from a different angle, the conclusion reached through many strictly geological evidences, that

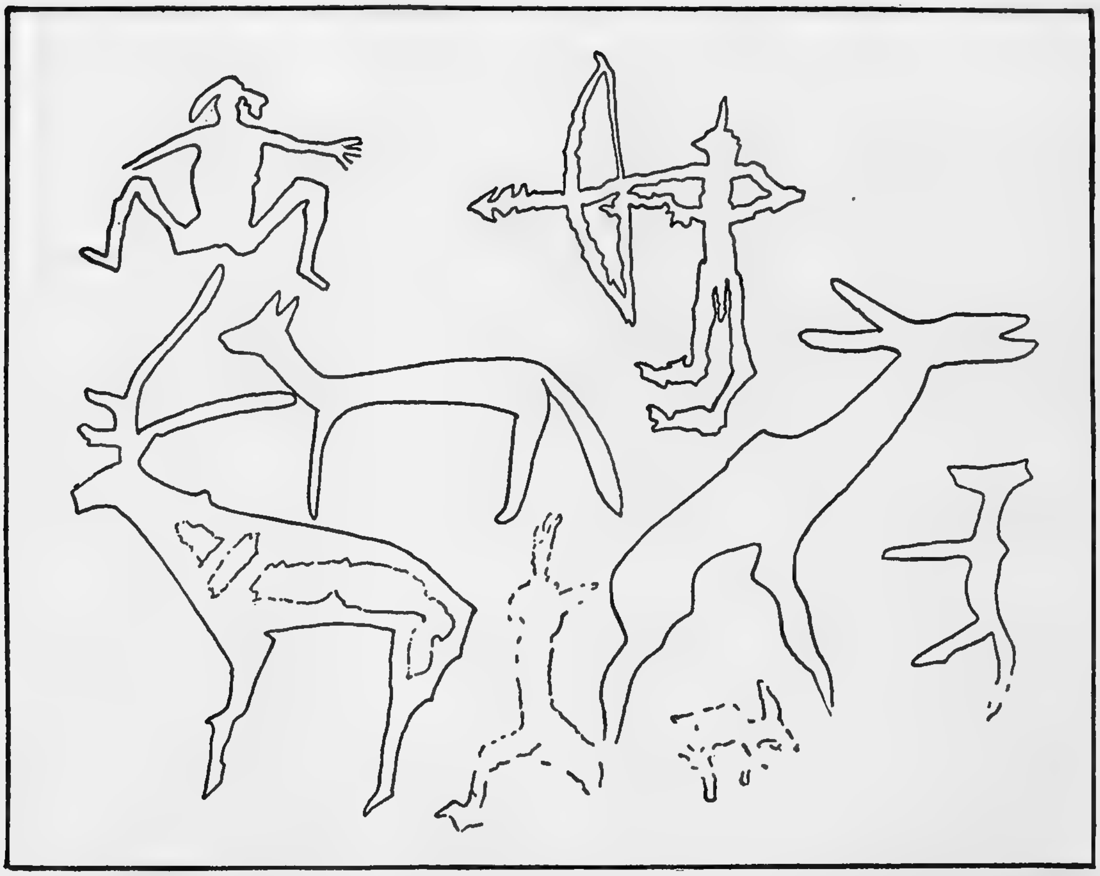


FIGURE 159.—Drawings cut upon a basalt block at Artsa Bogdo. These were made by a pre-Mongol people. They represent two human beings, one with bow and arrow, a large deer, a fox, and four creatures of doubtful identity, the largest of which resembles a moose.

central Asia has had changing climates for ages—sometimes favorable and sometimes most unfavorable to the living creatures that occupied it. Perhaps the changes were oft-repreated, and some of them may have been severe enough to drive the occupying races to neighboring territory. Short intervals of such exile would leave both a desire and an ability to return, but longer periods of banishment might keep a race out permanently. Perhaps in this way, changing climate has been vitally involved with the migrations of men and other races of living things. One such exiled race hunted the deer with the bow and arrow and indicated the climate of its time on blocks of basalt.

An abandoned dam

In a small valley ten or twelve miles north of Tsetsenwan, there is a well preserved earth dam more than a quarter of a mile long and about forty feet high. Except that it lacks a suitable spillway, it would compare favorably with a modern earth dam. It has undoubtedly stood for centuries. When it was made, why, or by whom, are quite undetermined; the Mongols of the region know only that it was not made by them, and in their traditions it was simply the work of a people who preceded them. No one would need a dam in this region at the present time; there must have been more water in the valley when the dam was built.

MEANING OF THE EVIDENCE

In assembling these items bearing upon the problem of climatic changes it has been our purpose to show that there have been such changes, and that the fluctuations have been many and of very unequal intensity and duration. Wet epochs that would favor the growth of crops of saplings in the Sain Noin forest are surely of a different order of magnitude from the wet period that favored the trenching of the great alluvial fan at Tiger Canyon. Lack of sufficient evidence has made it as yet impossible to correlate these climatic fluctuations, or to assign dates to them. The significant inference is that changes of climate—toward greater aridity on the one hand, and toward heavier rainfall on the other—have taken place, and probably will continue to take place, and that they have written their record upon the country and upon its living creatures.

PRESENT CLIMATE

Travelers tell us that forty degrees below freezing is a common winter temperature. Most of the wells freeze, and both men and cattle must depend upon snowfall for water. In the latter part of April, at least in southeastern Mongolia, a curious warm spell comes which lasts but a few weeks. It is followed by renewed cold weather which the Russians call the Icy Saints' Days, and which lasts into June. The hot weather begins in the latter part of June, and continues through July and most of August. Mr. Granger noted day temperatures ranging between eighty degrees and one hundred degrees F. for this period. The hottest night temperature was seventy-two degrees F., and most nights ranged below sixty degrees. Snows and frosts may be expected any time after September 1, but the true winter weather does not come, as a rule, until mid-October or November. The temperatures cited above were taken in the plains country at altitudes between 3,000 and 5,000 feet.

During the spring the winds are prevailingly from the west or north and are high and strong. In summer they are as a rule lighter and more variable, and often from the south. The fall brings the northwest and north winds again, and in winter the prevailing winds are from the north.

There is a light snowfall in the winter, with occasional rains in July and part of August. Cloudbursts such as those described by Walther for tropical deserts, are rare, if they ever occur, in the Gobi. As always, the rains and snows are heaviest in the mountains. Near the Arctic divide, the north side of the ranges receives the heaviest rainfall. Probably this is true in the Altai region as well. Rainfall increases again toward the Pacific divide, and here the moisture must come from the Pacific Ocean, so that the east and south winds should bring the rain. Forest patches appear on the well-watered northern slopes of the Arctic divide, while the southern slopes bear only grass. The grass-lands extend southward into the great basin, dying out very gradually into the sparse vegetation of the desert. A similar grass-land extends along the southern rim of the basin. It is nearly eighty miles broad from north to south, and is cultivated by Chinese farmers, who raise oats, millet, and potatoes.

Lacking all figures, we hazard a guess at the rainfall, based upon a comparison between the vegetation in Mongolia and that in similar latitudes in the United States. It probably varies from about twenty inches in the rich grass-lands to as little as eight or ten inches in the arid centers. Although we believe that the Gobi is in one of its arid cycles, no part of it is comparable to the extreme dryness of the Atacama desert of Chile, or the Hamada of Egypt.

A. SUN CRACKS AT TSAGAN NOR.

Shrinkage cracks in the sun-baked mud of a small playa near Tsagan Nor. The plates of mud are already nearly as hard as rock, and represent some of the new deposits that are now forming.

B. THE ABANDONED BEACHES OF TSAGAN NOR. THREE BEACHES MARKED BY GROWTH OF SHRUBS.

PLATE XLIII.

A. A PRE-MONGOL GRAVE, MARKED BY A RECTANGULAR ENCLOSURE OF ROCK SLABS.

B. GAP THROUGH THE RUINED GREAT WALL BETWEEN CHINA AND MONGOLIA AT THE CREST OF WAN CH'UAN PASS.

CHAPTER XXII

SUMMARY OF GEOLOGIC HISTORY

This is a preliminary summary. The work of the Expedition is far from finished. In due time we shall have to make revisions. Even though some of the statements may require considerable modification and doubtless many additions, we present the following geologic story with confidence that it will serve as a background for the studies that are to follow.

Our purpose is to assemble the historical facts established by our own and other work to the present time, and to treat the problem largely from the dynamic standpoint, emphasizing in succession the different fundamental processes that have made the Gobi region. It will be necessary sometimes to group several series of formations and to treat them as a unit representing one of the large segments of geological history characterized by a certain unity of physical condition or result. The significance of a particular geologic process that has operated through many different epochs may be seen clearly if treated as a problem in itself. It is our wish to make the course of events stand out as the center of interest, and those results are emphasized that lend themselves most readily to this end.

We have accordingly chosen to include in the summary the following major elements of geologic history, as exhibited in this region:

1. Ancient eras characterized by metamorphism.
2. Palæozoic marine history.
3. Mid-Mesozoic sedimentation, initiating the continental history of central Asia.
4. Development of basin structure, with its covering of later sediments.
5. A sedimentation summary.
6. The course of volcanism in Mongolia.
7. The deformation history of the Gobi region.
8. Prominent epochs of erosion.
9. Origin of the present topography.
10. Relation of geologic history to the development of man.

ANCIENT ERAS CHARACTERIZED BY METAMORPHISM

The formations belonging to the ancient history of the region before Cambrian time are exceedingly complex, highly metamorphosed, and give evidence of extensive modification (Fig. 161). Nevertheless, it is clear that the oldest formations were sediments—a great series of them—including the usual lithologic types represented by strata deposited in and with the aid of water. Doubtless many of them were laid down in the sea, and in that distant time there was probably an extensive marine history, now so obscured by later transformations that it cannot be read in much detail. There are great series of conglomerates, sandstones, shales, and limestones, repeatedly interbedded with one another. Those types of rock which indicate marine relations are found more abundantly in the earliest rather than in the latest groups of pre-Cambrian strata. The strata of the final stages of this early history seem to indicate a continental rather than a marine origin.

There are at least three great eras represented by quite distinctly different series of these meta-sediments, the oldest being by far the most changed from its original condition, while the latest one is much less modified. These divisions correspond roughly to those recognized in adjacent regions, particularly in China, where almost the same succession has been established. They may be tabulated from youngest to most ancient as follows:

1. The T'ai Shan Complex, as used by Willis in China, belonging to the Archæan era.
2. The Wu T'ai System, as used by Willis in China, belonging to the early Proterozoic era.
3. The Khangai Series, probably equivalent to the Nan K'ou System of von Richthofen and Willis and the Sinian System of Grabau, belonging to the late Proterozoic era.

The T'ai Shan complex

It is evident from field observations that there is a very ancient series of sediments which has been intimately invaded by igneous injections and intrusions of many kinds, chiefly of granitic type, and that the whole series, including the igneous members, has been regionally metamorphosed, extensively deformed, and exposed to destructive erosion. All succeeding formations were laid down on that erosion floor. The system now consists of injection gneisses, schists, and crystalline limestones which we correlate roughly with the T'ai Shan Complex of Bailey Willis, as described for China.

The Wu T'ai system

The Wu T'ai System, which follows, is represented by a great succession of schists, phyllites, and limestones that also were metamorphosed, folded, and eroded in their turn before the succeeding Khangai Series was developed. They are less extensively modified from their original condition and less intimately injected with igneous materials contributed to their present composition than is the older series beneath; but they are affected to a much greater degree in all these ways than any of the formations that follow. They must have been folded into mountain ranges, as were the formations of the preceding system, and it must have been from rocks of this kind, subsequently exposed to erosion, that the Khangai graywacke-slate series of the next succeeding period was formed.

The Khangai series

The formations, up to this point, have large developments of limestone, suggesting repeated advances of the sea. With the opening of the next period, however, and the beginning of the development of the graywacke-slate series, there must have been a more pronounced continental control and supply. There is a rather systematic change in the quality of the rocks of the series in different, widely separated localities, suggesting something of the geography of that time. Slates, with interbedded graywacke, predominate in southern and central Mongolia, graywackes and sandstones, with thin interbedded slates, are more common in northern Mongolia; while the assumed equivalent in central China is largely limestone. This, we believe, is the first series to have a continental significance, and it indicates that the sea lay to the south, with continental areas to the north and west. The outstanding characteristic of this ancient formation is its great extent and thickness, which is represented in the Khangai country and along the Tola River by many thousands of feet of graywacke. There is probably more than 20,000 feet of these strata still preserved. The condition at that time, therefore, must have been unusual. Graywacke is not an especially common type of rock, and any formation of such an enormous extent as this taxes one's imagination to account for it. During an incalculable period of time, conditions must have been reasonably constant over an immense area, to enable a formation of such striking uniformity to be developed.

This is the youngest, and also the simplest, of the very ancient series of more or less metamorphosed rocks. It is not everywhere heavily metamorphosed, however, and as it is not very intimately injected with volcanic products, although it carries many intrusions, its original character is easily determined. The series is folded into mountains, as were its predecessors, but the folds are simpler and more open, especially in the north, and there has been less internal, intimate deformation of the beds themselves. As a result, the graywacke or sandstone beds are only moderately metamorphosed; the shale beds between are transformed into slates or phyllites, and the limestones have become crystalline.

The triple character of this ancient section of geologic history is readily established, but some of its detail is obscure, and only its major features are as yet determined. It includes much the longest period of time, and it covers the eras of profound transformations of simple rocks. These have lost their original character, have been folded and faulted into new positions, sheared and recrystallized into new internal structure, and indeed, in most cases, into new mineralogical composition. They mark no less than three great sedimentation eras, each followed by a mountain-making epoch. There is a break between each two major series, or systems, representing erosion and a lost interval of time, but the unconformities are obscure, and much more work should be done with them.

The granite bathylith

The greatest igneous invasion recorded in Mongolia followed the mountain-folding of the graywackes, but it is not strictly a part of the Khangai history. It followed—and perhaps its activity helped—the deformations of that time, but the igneous rocks of the great bathylith, which in the next period, made great advances toward the surface through all these formations, have a history of their own.

In spite of this complicated history, and in spite of the mountain structure certainly represented, there is no remnant of the ancient relief at the present time. The rocks, planed down to a low monotonous relief, constitute the complex succession of formations of many kinds, which stand on edge for hundreds of miles and form the ancient crystalline floor on which all other sediments were laid down in central Asia.

PALÆOZOIC MARINE HISTORY

The Palæozoic history of central Mongolia is as yet almost a blank, for over great areas rocks of this age have not been identified. Only south of Sair Usu have we found formations which give satisfactory evidence of the conditions of that time. Even in these places, the land seems to have been undergoing erosion during the early part of the Palæozoic era, as no marine sediments have been identified older than the Mississippian or Dinantian period. There is thus a great break between the ancient rocks of the metamorphic eras and the rocks of Palæozoic age. Even as we write this, we realize that a very different correlation has been proposed by other observers in adjacent districts. Most of the Russian geologists regard the graywacke series as of mid-Palæozoic age. Some report the finding of Devonian fossils in them, in localities farther north and east. To this we have little to say, as we do not know the geologic structure of their country; but in central Mongolia these rocks, as far as we have seen them, are unfossiliferous, and have a structural relation to other series and to the known Palæozoics themselves that makes such a correlation appear improbable. Mid-Palæozoic rocks of such extent, and with the intimate relation to marine condition that seems to be demanded of that age, should carry determinable fossils. Pre-Cambrian rocks of the same type might well be normally without them. We have found late Palæozoic, marine fossiliferous strata infolded or infaulted as patches within graywacke areas, but this does not make the graywackes belong to their age. Jurassic strata are found similarly infolded in the graywackes. All that we can do is to place the Khangai series of graywackes and slates where the evidence thus far seems to favor,—that is, in the late pre-Cambrian rather than in mid-Palæozoic time.

In the interval between the deposition of the graywackes and the advance of the sea in late Palæozoic time, this portion of central Asia must have been dry land. During this time also, deep-seated igneous activity developed on perhaps the most enormous scale known anywhere in the world, when the Mongolian bathylith made its greatest advance and accomplished its greatest work in massive invasion, in upward stoping, and in penetrating the enclosing rock formations.

The known Palæozoic rocks are marine, and carry a characteristic fauna which clearly indicates their correlation. Limestones and dolmitic limestones predominate, while minor deposits of shale and sandstone are associated with a basal conglomerate—a thick series, but not by any means so great as those that preceded. The strata may have been much more extensive in former time, both in thickness and in areal distribution. They surely must have extended farther inland than they do now, even across the Arctic divide, and at that time they probably covered all other formations of the region. Where the limits were, however, is not thus far determined from the evidence available. It is clear only that they in their turn were folded, as the others had been, into mountain structure, and subsequently were eroded. They formed an important part of the southern mass that emerged from the sea at the close of the Palæozoic era, to become the core of the continent of Asia (Grabau, 1923 *d*, pages 408, 468). Since Permian time, this portion of the continent has never been resubmerged.

How great an interval of erosion followed is not certainly known, but it is clear that a long period, represented only by an extensive unconformity, intervened before the deposition of the succeeding formations that lie upon the post-Permian erosion surface.

MID-MESOZOIC SEDIMENTATION INITIATING THE CONTINENTAL HISTORY OF CENTRAL ASIA

The Mesozoic era is represented in Mongolia by two formations of very different age and structure, separated by one of the most pronounced unconformities of the whole geologic column. The formation above the unconformity is known to be of Lower Cretaceous age, and initiates an entirely new cycle of events, different enough from those preceding to be regarded as a new division of history. Therefore, this formation is treated with the overlying Tertiary formations as a new structural unit, which we have referred to as the "Later Sediments" of the Gobi region (Berkey and Granger, 1923).

The Mesozoic formation beneath the unconformity, has, at best, a somewhat obscure historical standing. It is clearly of continental type, but carries almost no diagnostic fossils. The few traces found are obscure and poorly preserved plant remains, which accompanied the making of coal. The formation is enormously thick in certain localities and entirely wanting in other extensive areas (Fig. 160). It may never have been developed over the whole region, but there is a constancy in lithologic type and structure that indicates a certain unity of physical history. The sediments are chiefly coarse conglomerates and sandstones, most of which were rapidly accumulated by running water and shifting currents. A considerable proportion is well bedded and uniform in grain, indicating deposition in lakes. The formation is wholly non-marine. The prevalence of coarse material, especially pebbles, through strata thousands of feet thick in widely separated areas, supports the hypothesis that these sediments were developed as isolated deposits in subsiding areas adjacent to uplifted fault-blocks, the destruction of which must have furnished the rapidly accumulating material. It is apparently impossible for such materials to have been transported great distances from constant sources, but it would be possible to supply material of this kind from a series of nearby sources, during the progress of deformation that renewed the relief. It is probable, therefore, that the formations known as Jurassic strata in the Gobi region and in Siberia and China were never continuous, and that no two localities bear exactly equivalent formations. Between the areas of deposition, there probably were divides whose destruction furnished the supply of detritus. Some of these ridges have persisted to the present time, for the erosion that followed was more destructive to the loose Jurassic sediments than to the ancient divides of crystalline rocks. The only remnants of the deposits, therefore, that are still preserved, lie in depressed areas, which have been faulted or warped down in later time, and thus have been protected from the general peneplanation that preceded the Cretaceous period. The landscape of Jurassic time was probably a series of mountains and intermontane basins. But how they were distributed one can not make out with certainty, because there are so few remnants of the strata still preserved from erosion and not now covered by later deposits.

In spite of the probability that these sediments do not exactly match in different areas, they do all fall into a certain historical position. They lie in the mid-Mesozoic. They follow a long period of erosion that is itself to be subtracted from early Mesozoic time, and above them is another erosion break of enormous proportions, preceding the Lower Cretaceous period. Between these two great breaks occurred the sedimentation which, for convenience, is referred to as the Jurassic period. It may possibly extend down into Triassic time, but it surely does not continue to the end of the Jurassic. In the Mesozoic era, therefore, the continental character of central Mongolia became firmly established, with two long periods of erosion and a period of continental deposition represented before Lower Cretaceous time.

Folding and faulting and extensive igneous eruption closed the constructive period, and pre-Cretaceous erosion beveled across all these structures in making the great peneplane which reduced the Jurassic block-mountains, together with all preceding rock formations, to a surface of low monotonous relief, which has become, for all succeeding time, the floor or basement on which the later sediments were laid down. Viewed from this angle, the mid-Mesozoic strata become a part of the complex floor. They are the closing incident in a complex series of events that ended the mountain-folding of central Asia. Since then the strata of central Mongolia have not again been crumpled into mountain folds. All rocks of the ancient floor have been deformed in this way, but with the making of the great unconformity beneath the Cretaceous beds in mid-Mesozoic time, the central core of the continent of Asia became stabilized against lateral crowding, and its long history of repeated mountain-foldings has been succeeded by an unbroken history of simple warpings and faultings, in which elevation and subsidence have dominated.

DEVELOPMENT OF BASIN STRUCTURE WITH COVERING OF LATER SEDIMENTS

Following the erosion epoch which closed Jurassic time, the region of central Mongolia, which by this time had been reduced almost to a peneplane, was lifted and warped into a broad basin with inland drainage, and a long period of alternating localized denudation and deposition was commenced, which has lasted to the present day. The extent and distribution of local warpings of the earliest time may not be determined, but it is clear, from the interruptions recorded in the deposits and the peculiar distribution of the sediments marking the different horizons, that intermittent warping has characterized the whole of post-Cretaceous time. The downwarped areas received sediment washed from the upstanding masses, and thus became minor fills of sediment, separated from one another by warped or faulted divides of hard rock (Fig. 160).

All the smaller basins and divides have a tendency to shift as the intermittent warping is renewed so that many areas which were formerly covered have subsequently been stripped; areas once covered with greater thicknesses, have

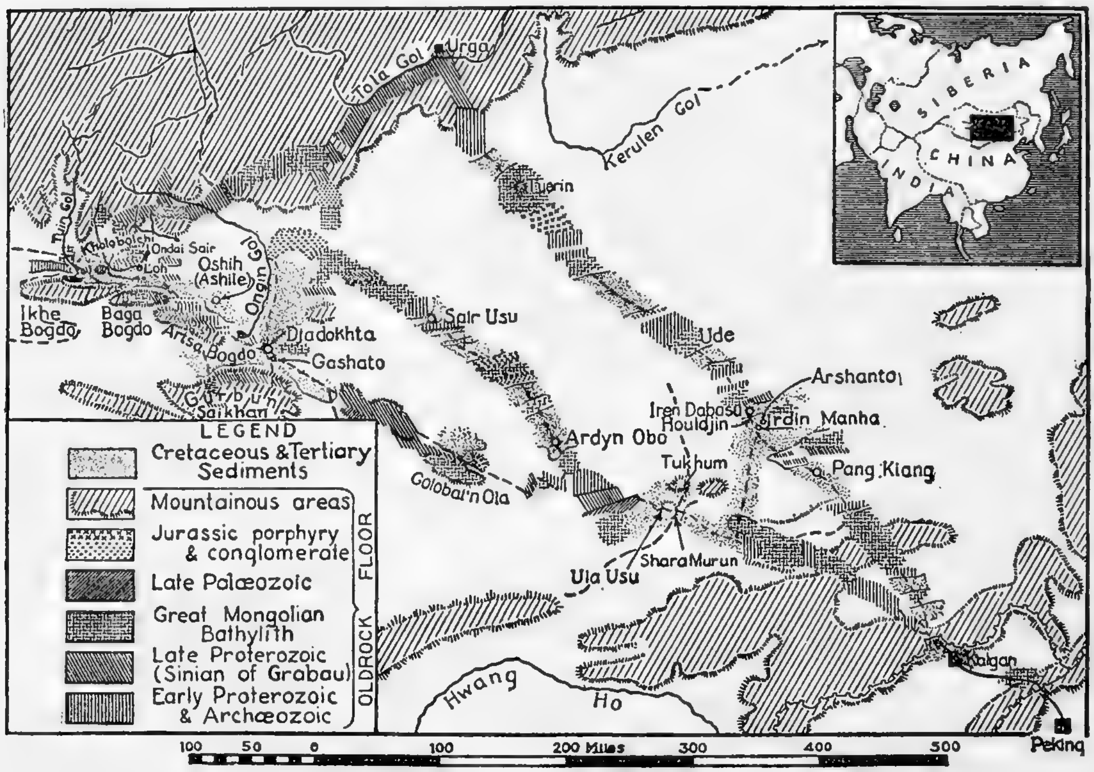


FIGURE 160.—Sketch map of central Mongolia, showing geologic units along the traverses. An attempt has been made to distinguish the different major groups of floor rocks along the route of travel, by different patterns. The younger basin sediments along the same routes are stippled. In the untraversed regions, the white areas represent lowland areas, as distinguished from the more mountainous tracts.

suffered partial denudation, while other bare areas have received deposits. Thus it happens that the geologic column of any locality is always only a partial one; it is always broken; and in most cases, it carries but a fraction of the sedimentary representatives of the whole time interval.

The greatest break in the later sediments is that which marks the transition from Cretaceous to Tertiary age. All strata beneath this erosion break are more deformed than are those which lie immediately above. Apparently, the region has progressed to greater stability and simpler deformation with the progress of time, even within the period of later sedimentary deposition. Doubtless the dynamic cause is the same for all. There must be changes going on beneath the surface at some unknown depth,—changes that tend in the course of time to modify the supporting structure of the crust. It is probably, in essential quality a volcanic activity, and results in changes of density as well as in a thinning of the roof, so that the readjustments are probably isostatic. Basaltic outbreaks habitually accompany these deformations—even those of latest time—suggesting that the hidden volcanic processes beneath are not only genetically connected with the volcanic outbreaks themselves, but are vitally connected with the deformations that accompany or precede them. This type of deformation has been so widely distributed, in both time and space, and has been repeated so many times, that it is the most characteristic dynamic feature of Cretaceous and Cenozoic time. Deposition in the depressed areas and erosion of the more elevated areas are merely incidental accompaniments of the deformation.

The establishment of inland basin structure, and the renewal of warping from time to time, have had profound effects upon the climate of central Asia, tending to make it more arid as the uplifts grew. The same processes have continued to the present day, and the present surface represents a considerable epoch of erosion, which has prevented deposition of beds of Pleistocene age, except in certain minor areas. It is under such conditions that the animal and plant life existed whose remains now make these sedimentary remnants important fossil fields.

The general dynamic history of the Cretaceous and Tertiary periods is, therefore, readily pictured, but in detail it is much more complex, and the building of a complete sedimentation column for the later sediments, as well as the making of a complete story of the dynamic movements of that long period of time, must await the assembling of a still larger body of data. At least the major features of the story are well established; with them, perhaps, one must be content until the work is finished.

A SEDIMENTATION SUMMARY

The oldest rocks known in the Gobi region are of sedimentary origin. All these very ancient formations, however, are extensively metamorphosed and, in most places, also extensively injected with igneous material. This has so modified the original character that it is not possible to determine very accurately the precise nature of the sediments themselves; but it is clear that, from the very beginning of the geologic record, there have been strata of the nature of sandstones and shales, limestones and conglomerates, just as there have been in succeeding periods. The presence of limestones on a large scale supports the interpretation that these strata were marine; but evidence of any other sort is lacking throughout the whole of pre-Cambrian time, except in the very latest system, that of the graywacke-slate series, which is essentially continental. There are thousands of feet of pre-Cambrian sediments, which can be subdivided into at least three major divisions representing successive time periods. Not a trace of organic life in the form of fossils is to be found in any of them, unless it be in the uppermost slaty layers of the graywacke-slate series, where we find obscure traces of forms that are believed to be of organic origin. The determination of sequence and relative age, therefore, depends wholly on their structural relations in the field and their relative complexity of petrographic condition,—it being assumed that, on the average, the more complex petrographic types represent the more ancient systems, and the simpler petrographic types, the younger. Originally even the most complex injection gneisses must have been simple rocks, probably chiefly sediments, and we must regard all the many changes in petrographic quality as indications of as many steps in the subsequent history of the formation.

Stripped of these later complexities and additions, the whole group of pre-Cambrian systems would look simple enough. But each older series of rocks has had a longer experience, with increased confusion of its original characters. They may be listed in groups, indicating their original, metamorphic, and injected condition, as follows:

Original Sediments	Folded and Metamorphosed Products	Igneous Meta-Products
Conglomerates, quartz sandstones	Quartzites, quartzite schists, quartz-mica schists	Injection gneisses, banded gneisses
Arkosic and lithic sandstones	Graywackes	Graywacke schists
Shales	Slates, phyllites, mica schists	Injection schists and gneisses, banded gneisses
Limestones	Crystalline limestones and dolomites, marbles	Silicated and silicified meta-limestones and dolomites

The Palæozoic system is not largely represented in the Gobi region, and probably never was represented by any formations preceding the Mississippian, or, at the earliest, the Devonian. Basal conglomerates were found in the Sair Usu region, immediately below the Mississippian. The sedimentary succession is marine; the conglomerates and sandstones at the base are thin and are succeeded by a thick series of limestones and dolomites in that district, with less prominent shaly members; the chief sedimentary type is a granular, fossiliferous limestone. At Jisu Honguer, the Permian beds begin with a basal conglomerate of well-rounded pebbles, followed by sandstones and shales with intercalated lenses of limestone. The limestones contain the only fossils thus far found.

At the close of Palæozoic time, the sedimentation habit was changed, and marine conditions ended permanently. After a long interval of profound erosion, sedimentation was established again in mid-Mesozoic time, with a series of continental deposits. These are dominantly conglomerates and pebbly sandstones, and sandstones of strongly bedded character. In favorable places, these beds total many thousands of feet,—perhaps twenty thousand feet, in the best sections. There are no limestones, and there are few shales. The character is that of alluvial fans, delta deposits, stream wash, and intermontane lake deposits. No fossil content has been recovered except traces of plants and coal. It is a striking fact that the sedimentary type is so definite in central Asia, and so much alike in localities scattered a thousand miles apart. It seems to us that the formations never could have been continuous, but that they were normally discontinuous, representing isolated sedimentation basins, which, because of the constancy of physical conditions over wide areas, produced similar results in each locality where sedimentation was going on. These conditions terminated with renewed deformation and a period of erosion, which reduced the region to a low rolling surface. With these mid-Mesozoic deposits, the whole sedimentation history of the formations that constitute the ancient floor of the Gobi region of central Asia was completed.

All formations since that time have a simpler origin and structure. The continental habit was retained, but it took on something of its present-day features, in that sedimentation was carried on in interior basins which have become in later times desert-like, and which, indeed, may have been desert-like in many earlier epochs. All these strata lie on the eroded floor of the mid-Mesozoic and earlier formations, and constitute a succession which continues from earliest Cretaceous to the present time. The sediments are chiefly gravels, sands, silts, clays, and shales, with rare limestone layers. Inland lakes were more common in the earlier epochs, so that muds which now appear as fine paper-shales, were characteristic. These do not occur in such prominence in the later epochs, where clay-sand mixtures predominate, though sands and gravels are common. These types have been repeated in successive periods and in widely separated basins, so that there is an aggregate thickness of more than 12,000 feet; but only a small fraction of this total appears in most of the individual sediment-basins or gobis. The conditions which were initiated at the beginning of Tertiary time have continued to the present,—slow and moderate warping and sedimentation, followed by long intervals of erosion. Alternations of these two sets of conditions succeeded one another throughout Tertiary time, and the sedimentation habit still continues, almost as it began, covering altogether an enormously long period of comparatively stable conditions.

The succession of sediments, marking this later history and constituting the succession lying on the ancient erosion floor, is tabulated on page 371.

DEVELOPMENT OF VOLCANISM

As pointed out in the preceding section, the most ancient rocks identified are interpreted as metamorphosed sediments, but with them are associated very ancient igneous injections and intrusions, some of which must date back to times almost as ancient as the sediments themselves—for some of the igneous materials are as complexly metamorphosed as are the sediments with which they are associated. Granites are most common, but there are diorites and rocks of still more basic type, such as pyroxenites and peridotites that have been changed to serpentines and serpentinous schists. Although very long volcanic history preceded the more spectacular intrusions of the great Mongolian bathylith, the history of volcanism in central Mongolia is, we believe, essentially a simple story, centering around the development of the bathylith.

Deep-seated magmas

In early Palæozoic time, or, at least, after the deposition of the Khangai graywacke series, there developed in central Mongolia a great underlying bathylithic magma, whose uppermost portions in later solidification became a granite. In hundreds of places, scattered over a total area of hundreds of thousands of square miles, this bathylith is now exposed by erosion which has cut deeply into the old roof. At many places the magmatic activity was vigorous enough to penetrate far into the overlying strata. Doubtless, also, great masses of the roof were engulfed and tended to sink into the plastic magma, to be more or less completely absorbed and transformed. At favorable places, substances were given off from the magma, in the form of emanations and solutions which, penetrating the overlying formations, attacked and modified the rocks through which they passed. Large amounts of the hot solutions were trapped within the enclosing formations, thus adding to their original complexity. This process is probably responsible for the structural confusion and complexity of composition that characterize the ancient series.

In still more ancient time, before the maximum development of the great bathylith, there were igneous activities of a more limited sort, which we believe were simply the forerunners of the same slowly developing volcanism. It would not be unreasonable to believe that the igneous injections noted in the earliest sediments, which were metamorphosed long before the time of the Mongolian bathylith, actually came from the same deep-seated volcanic centers, and that they represent the first steps in an age-long volcanic history which should be regarded as a unit. In this view, the various evidences of volcanism in the Gobi are but different exhibits, reaching separate expression at successive stages in the normal development of a great subcrustal igneous mass. The volcanism of early Palæozoic time is marked by the maximum development of bathylithic granite. This has many petrographic variations, but it is prevailingly a coarse-grained biotite granite of acid composition, and usually of a massive structure. It extends, with amazing uniformity for enormous lateral distances, and the local variations are certainly no greater than one should expect as a result of differentiation within the mass itself, and of syntectic modification produced by absorption of material from the roof. It is one of the most extensive and uniform bathylithic masses known anywhere on the earth.

Subsequent volcanism takes an entirely different aspect; nevertheless, it may be only another expression of the same history. All the succeeding products may represent only the solidifying, differentiating, and residuary activities of the bathylithic magma beneath. The chief later expressions are three: (1) serpent-form dikes, (2) brittle porphyries, (3) basaltic and other lavas and pyroclastics.

Serpent-form dikes

An immensely complicated series of dikes cuts the bathylithic granite and adjacent portions of the roof. These are the so-called serpent-form dikes that have been described in Chapter V. They are of great petrographic variety, and are undoubtedly of different relative age, for they cut each other in a most confusing way. Because of this great complexity, they are most easily interpreted as special products given off during the differentiation and cooling of the underlying mass. They are a type by themselves, not to be confused with any others, and they probably developed early in the solidifying stage.

The brittle porphyries

A series of brittle porphyry intrusives characterizes certain areas. They are granite and syenite porphyries and, more rarely, dioritic and monzonitic porphyries of great minor variety. Most of them are large, irregular intrusive masses, either cutting Jurassic strata or occupying ground between Jurassic strata and adjacent more ancient types. Some of them seem to be connected with the deformation history of that time, whereas others must be much older. They are remarkably similar over territory as widely separated as are the individual deposits of Jurassic strata. It is most unlikely that such similarity could have come about except under the influence of some regional control.

The simplest one to suggest itself is the great bathylith. The porphyries are probably only another expression of activity marking a new stage in its history. They appear to represent deformation and outbreak in a period succeeding the maximum development of granite. Since that time, nothing similar to them has been produced on such a scale. Later field observations, however, indicate that there was an immense development of porphyries and flows preceding the maximum granite invasion. The porphyry problem requires additional study in the field.

Basaltic and other lavas and pyroclastics

In later time, only one other type of volcanism is recorded. This is represented by flows that are dominantly basalts, though rhyolites, trachytes, and even pumiceous glasses also occur. Basalt flows have spread over thousands of square miles. Like their immediate predecessors,—the brittle porphyries,—they seem to be intimately connected with the deformations of the region. Although of Cretaceous and Tertiary age, they may be only another expression of the closing stages in the life history of the great bathylith. The upper portion is acid in composition, and was long ago solidified; the deeper portions ought to be more basic, and there may still be highly heated portions available at times for extrusion. Perhaps these localized remnants and their activities are largely responsible for the crustal adjustments of later time. Corresponding to the flows, there are extensive beds of ashes and tuffs, widely distributed and repeated at several horizons. They seem to have the same significance as the flows. With the basalts, the whole history of volcanism has been run, from earliest times to the present. It is a fine example of an igneous history that does not miss a single period from the bottom to the very top of the column, wherever sediments are represented.

DEFORMATION HISTORY

The deformation processes that have affected this region have resulted in a great variety of expressions. They have included continental epeirogenic uplift and subsidence, mountain-folding, internal metamorphic reconstruction, local fault-block displacement, and simple warping, and these major structural effects have been accompanied by the usual minor structural modifications.

Epeirogenic movements

Epeirogenic movements have more than once submerged the region beneath sea level so that marine sediments were deposited, and later have raised it to continental position so that erosion could take place. Each unconformity, up to and including the Palæozoic era, must represent epeirogenic movement of a profound character. The latest of these breaks is at the end of the Palæozoic; another, at the end of the Proterozoic, follows the development of the graywacke series; and a third, represented by the conglomerate in the base of the graywacke series, apparently separates the Wu T'ai from the Sinian system. A fourth is indicated between the T'ai Shan and the Wu T'ai. In later time, there is only one major break—the so-called "Great Unconformity," between the folded conglomerates and sandstones of Jurassic age and the overlying, simple, Lower Cretaceous strata. Doubtless there is represented in this break important epeirogenic movement, but it is not of the same significance as the previous ones, because it does not involve depression beneath sea level. The great breaks are indicated in the tabulation of major elements of Mongolian geology (Fig. 130, page 301).

Orogenic disturbances

All the strata, of every system up to and including the mid-Mesozoic sediments of Jurassic age, have been folded. There are five such major units, with unconformities of more or less profound significance between them. It is not possible, however, with present information, to assert confidently that separate mountain-folding affected each system as it was developed; but the strikingly different structural condition of each, and the much more complex condition of each older one, suggest emphatically that an additional mountain-making experience is one of the reasons. In the older systems, folding is complicated by metamorphism and very extensive igneous intrusion. This applies particularly to the T'ai Shan system and to the Wu T'ai, in both of which the folding is intense and essentially isoclinal. The next system, the Sinian, is more openly folded. In all three of these ancient systems, judged to have preceded Cambrian time, folding is the major deformation process. The same type of deformation also affects the strata of Palæozoic age.

Probably regional folding came to an end in the early epochs of the Mesozoic era, but the Lower Jurassic strata are moderately folded and are limited by large faults. The character of the sediments (see page 292) suggests that they were laid down in separated basins between uplifted fault-blocks. After the close of the period of active deposition, there probably was a renewal of fault movements, which crowded and somewhat folded the Jurassic strata between the blocks of oldrock. Thus the mid-Mesozoic disturbance is of a mixed faulting-and-folding character. With it, folding comes wholly to an end in central Asia, and all orogenic movements of later time are simple warpings and faultings.

Warping

All the sediments from Lower Cretaceous time to the present lie on the upturned, eroded edges of older strata which represent peneplaned mountain ranges. The strata of Cretaceous and Tertiary time are deformed also, but never in this region by simple folding. In places they are disturbed so much that they stand on edge, but this is due to sharp flexures or to drag accompanying faulting, and is confined to narrow zones. Much commoner are the great downwarped depressions and upwarped divides, which vary from only a few miles to more than a hundred miles across. Judging from the attitude of the strata which remain, there was more pronounced and more widely distributed deformation in Cretaceous time than in the Tertiary, for the Cretaceous beds are much the more disturbed. Large areas of Tertiary strata are very little deformed. Inspection of a series of localities, scattered over the whole central Mongolian region, discloses indisputable evidence that gentle warpings have taken place, not quite continuously, but at frequent intervals, and have been in operation virtually to the present time. The upwarpings have brought portions of the ancient floor to the surface, and sometimes to elevations much above the average level, so that a rugged topography is developed on them by dissecting streams; the downwarps forming local basins have retained downwashed sediments, thus making the gobis. The floor of a gobi is the result of both erosion and warping, and its basin character may be due chiefly to erosion, or chiefly to downwarping, or in some measure to both (Figs. 154 and 155, page 369). Where the sum of erosion and warping is downward or negative, a basin containing sediments is preserved, but where the sum of all warping and erosion is upward or positive, the ground is arched and the ancient rocks lie bare, stripped of any sediment that may once have covered them.

Virtually no places thus far discovered have suffered continuous downwarp so that they contain a complete unbroken section; probably, also, none has recorded continuous upwarping. Much commoner has been a combination of upwarpings and downwarpings, which has given opportunity for deposition, followed by partial denudation. Every formation, up to and including strata of Pliocene age, is affected by these movements, and even the erosion plane that bevels the Pliocene beds, and doubtless represents a portion of Pleistocene time, is itself warped. There is reason to believe that this kind of movement still continues.

Thus a great change in the method of deformation appeared in north central Asia in Cretaceous and Tertiary time. Folding characterizes the pre-Cretaceous periods from beginning to end, whereas warping with local faulting characterizes post-Jurassic time.

Faulting

Faults are conspicuous local features of the region, and doubtless have accompanied the deformations of every era; but those of the earlier eras, when folding predominated, are obscure and have no effect on the major features of the present topography. Faulting must have been important in Jurassic time; but the scarps have been planed away by subsequent erosion which reduced the region to a general base-level. The block-faultings of later geologic time, however, are much more conspicuous and important.

Some of the movements of Cretaceous and Tertiary time, which are in part of block-fault type, are still preserved in the landscape, and account for the most prominent mountain ranges of the Gobi region. The Altai mountain ranges traversed by the Expedition, with many associated uplifts of much less relief, are all of this type. The major units of the Altai system which have been examined thus far by the Expedition are the Baga Bogdo, the Artsa Bogdo, and the Gurbun Saikhan ranges. There are many minor ones of similar habit, among them the Uskuk block and the unnamed range east of Uskuk.

In general, the present-day mountains of Mongolia are of two types: the fault-block, which owes its relief to direct uplift or tilting, and the eroded arch. Although the internal structure of the fault-blocks is as complex as the oldrock floor, and includes folded rocks, the mountains themselves are not folded mountains. The other type of mountain is the result of the erosion of great upwarped arches. They have been raised to such elevation and have persisted through such enormous lengths of time that the ordinary processes of erosion have carved mountain relief on them. Folded strata are included, but the mountains are not due to folding. They are only the end-product of erosion on one of the greater upwarps, which probably has had almost continuous positive movement. This is the structure of the Khangai ranges of Sain Noin and the Gangin Daba range of the Tola River country.

Metamorphic deformation

The rocks of the pre-Cambrian systems were so deeply buried when the great mountain-making revolutions were taking place, that in addition to the gross deformations of folding and thrusting, a series of intimate internal changes was produced within the rocks themselves. These changes include mashings, shearings, recrystallizations, and the long list of complex alterations that are best understood as the result of dynamic metamorphism. The changes characterize particularly the two most ancient systems, the T'ai Shan and the Wu T'ai. They are much less pronounced in the later rocks, although the weaker members of all the folded series are sheared and somewhat recrystallized, so that a slaty cleavage cuts across the original bedding-planes.

Grouping of deformation products

From the standpoint of deformation, it is possible to recognize three great types. The oldest includes the T'ai Shan and the Wu T'ai systems, which are folded and internally metamorphosed. The second type is characterized by folding, with moderate internal deformation in the oldest portions and some block-faulting in the youngest ones, but folding is their dominant deformation feature. This type of deformation characterizes the graywacke-slate series, the strata of Palæozoic age, and the mid-Mesozoic strata. The third and latest type is characterized by repeated warpings, occasionally accompanied by prominent block-faulting; either expression reaches, in extreme cases, a relief of mountainous proportions. This type of deformation belongs to post-Jurassic time and continues to the present, with some of its most pronounced deformation effects belonging to very recent geologic history.

Epochs of erosion

The most prominent erosion breaks in the geologic column are those between the major systems of the pre-Cambrian, that which represents the early and mid-Palæozoic, and those which cover the early Mesozoic and the late Jurassic (See table, page 301). Each of the great breaks undoubtedly represents an enormously long erosion interval, for during each of them, relief features of mountainous character must have been leveled down almost to the smoothness of a peneplane. This can be determined with greatest certainty in the case of the Jurassic unconformity, which, because it shows the greatest structural break in the whole series and forms the ancient floor on which all later sediments were laid down, has been referred to in the geologic column of Mongolia as the "Great Unconformity." If we are right, however, in correlating the Khangai series of graywackes with the late pre-Cambrian or Sinian, there is a longer break between the Khangai strata and those of Upper Palæozoic age than can be accounted for in the Great Unconformity, for the total absence of deposits representing the Cambrian, Ordovician, Silurian, and Devonian periods must mark an enormous erosion interval—longer than any later ones.

The significance of the break between marine Permian beds and the continental sediments of Jurassic time is likely to be overlooked, because, in the limited distribution of the Palæozoic strata, little chance is given for direct study of structural relations. But the mere fact that formations as thick as the remnants preserved at Sair Usu and Jisu Honguer do not exist over immense areas which formerly they must have covered, is in itself an argument for a most profound erosion. Probably both the post-Permian break and the early Palæozoic hiatus represent longer intervals than the Great Unconformity itself.

There is no way of determining how profound may be the breaks between the pre-Cambrian systems. The difference in quality of the strata

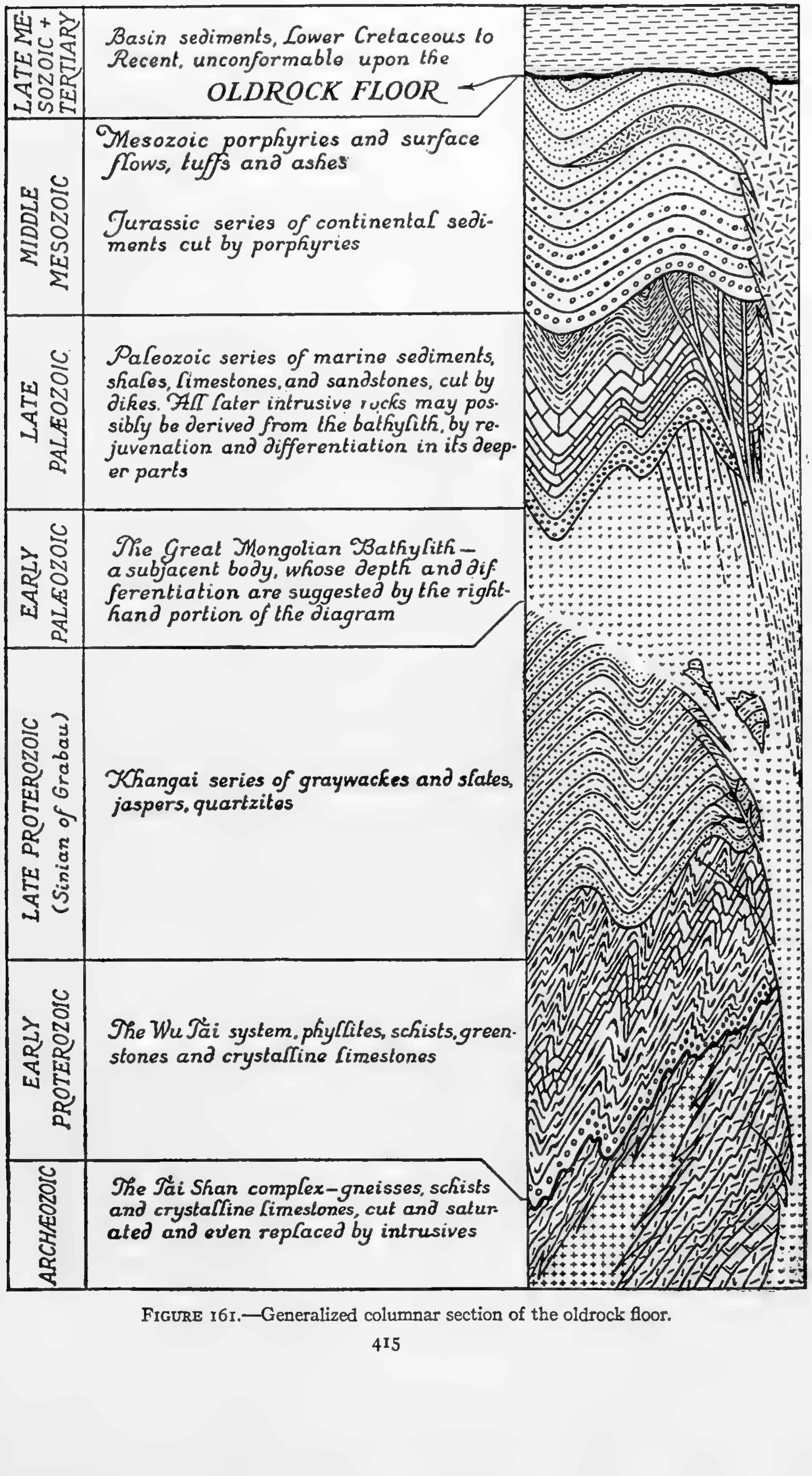


FIGURE 161.—Generalized columnar section of the oldrock floor.

themselves is a partial indication of great difference in age; but this may be due in part to superposition, with a more pronounced metamorphic effect in the deeper layers. It is clear only that there are breaks, that there is a simpler structure in the higher systems than in those below, and that there must be intervals between them.

Disconformities

All the earlier breaks are extensive as compared with the later ones. They represent greater lengths of time, and mark periods of regional erosion between more profound deformations than took place in the later epochs. In post-Jurassic time, however, with a change in the deformation habit to gentle warpings and occasional flexures and faults, the erosion breaks became simpler, less extensive, and more numerous. We have mentioned that the Cretaceous sediments are generally more deformed by tilting, flexing, and faulting than are the overlying Tertiary beds. There is everywhere a break of large time significance at the base of the Tertiary, representing the greatest physical and faunal changes recorded in all the later sediments.

There are minor breaks within the Cretaceous and within the Tertiary. The three well-recognized Cretaceous horizons—the Oshih-Ondai Sair, the Iren Dabasu, and the Djadokhta—are characterized by distinct faunas, and must be separated from one another by long intervals. In the Tertiary, the breaks are of local, not of regional significance; some have continued for long intervals, and some have been short, but no systematic relation between the intervals at different localities has yet been discovered. For example, at Iren Dabasu, slightly disturbed Cretaceous beds are followed by early Eocene, upon which rest Oligocene gravels. But only twenty miles farther south, the Oligocene beds are absent, and the early Eocene is followed by a later Eocene horizon which is lacking at Iren Dabasu (Fig. 102, page 201). The generalized diagram, figure 156, page 370, has the advantage of showing how many breaks there are and of how variable length, at each camp where formations have been named; but the diagram underestimates, rather than emphasizes, the relative length of the intervals between the deposits. In some places, the earlier Tertiary beds are more disturbed than the later ones, and the angular divergence between the two suggests a profound unconformity. But it does not have this significance; there is no regional unconformity subsequent to Cretaceous time. The Tertiary breaks are local, and they vary in area and in the time-interval which they record. Those portions of north central Asia which have been continuously upwarped, such as the Khangai mountain region, have a greater significance and probably mark the early stages of a future unconformity. The strata, which are being laid down now on the eroded lower flanks of the Khangai arch, preserve this unconformity, and measure an erosion break that stretches from Jurassic time to the present. This break may represent something akin to the Great Unconformity; but the large majority of erosional breaks in the Gobi region affect the sediments only, and are essentially local disconformities, of minor significance in the history of the region.

ORIGIN OF PRESENT TOPOGRAPHY

In spite of the apparent monotony of the Gobi region, there is an immense diversity of feature, due to widely different geologic processes and structural control. The most noticeable features of the Gobi are smooth, almost level stretches of country underlaid by simple sediments, which are the true constructional plains. They are separated by more rugged divides, composed of ancient deformed and crystalline rocks. This sort of monotony is broken by mountains of magnificent proportions. All the surface elements —heights, flats, and hollows—lie on the vast warped surface of a great inland basin, with a north-south limit of more than six hundred miles and an east-west extent of more than one thousand miles (Fig. 4, page 43).

Although it is true that this great basin region has been one of deposition from the beginning of Cretaceous time to the present, only the minor surface features are depositional. They include alluvial fans from the uplifted mountain blocks; stream deposits along valleys, where sediments are dropped as the waters disappear in the sands of the desert; and wind-blown sands, in the form of dunes and thin sheets, shifting in low, bush-grown mounds over broad stretches of open country. All are small and insignificant, and the major features are of strictly erosional origin, the destructional work of wind, water, and weather. They appear as erosion planes, dissected erosion planes, and as uplifted, dissected areas that owe their relief to forces within the earth, and their ruggedness and minor detail of feature to the destructive work of surface agents. The great basin itself is a diastrophic product, and the minor basins within it are of the same origin. The same general causes account for the Altai fault-blocks and the great arch of the Khangai, and for some of the minor relief structures such as volcanic cones and lava fields.

On these primary relief elements, erosion has produced its usual variety of relief. It has made mountainous country by deep erosion of great uplifted arches; it has produced exceedingly rugged topography on upfaulted mountain blocks, leaving only traces of the ancient smoothness that must have marked the original uplifted floor; and it has beveled wide areas of both the sediments and the harder rocks, wherever stability has been maintained for a period sufficiently long, producing widespread planation that makes certain great stretches of Gobi country look as monotonously level as a floor. Even these have been interfered with in some places by the inner forces of the earth, so that some of the planes are warped into broad domes, while others have sagged into basins.

The simplicity of the record of deposition is disturbed, also, in two other ways. The present is an epoch of dissection. Stream courses have carved channels across country, and many districts are intricately dissected into badland topography, such as marks the work of rain in any dry region of soft strata. In addition to this, the wind has gouged out hollows both in the sediments and in the crystalline rock. The hollows are erratically distributed, are of varying shapes, sizes, and depths, and produce a variety of erosional topography, which is not encountered except in desert regions.

The whole combination of features gives a variety to the Gobi region not at first suspected. To the average traveler, it may seem to be a hopeless waste, a discouraging and endless monotony of open country, but to the scientist, who looks behind the scenes, it is a geological paradise—an exhibit of processes, structures, and forms, probably unsurpassed elsewhere on the face of the earth.

RELATION OF GEOLOGIC HISTORY TO THE DEVELOPMENT OF MAN

The Third Asiatic Expedition has often been referred to as the Expedition in quest of early man, and there is a persistent demand for some explanation of that side of its investigations.

No fossil traces of primitive man were found enclosed in any of the strata of the Gobi region during the seasons of 1922 and 1923, but this fact does not necessarily prove the futility of further search. A few stone artifacts have been collected, some of which have a primitive palæolithic aspect, while the majority are surely neolithic types, but they were found lying on the surface, not enclosed in sediments. For the present, therefore, they must be interpreted as proving the existence of primitive cultures; but they do not necessarily prove the antiquity of man's entry into this region, and they give no evidence concerning man's evolution. It may or may not be that the central regions of Asia were favorable for the evolution of man in his early stages of development. But the history of migrations, in so far as they are known, and the geographic distribution of different races of people seem to favor the assumption that central Asia may at least have been an important factor in the dispersal of races. Much better results were obtained in 1925 when the cultures of the Dune Dwellers of Shabarakh Usu were recovered from the sand-filled valley in the district of Djadokhta; but a discussion of that discovery must be reserved for later publications. It is sufficient at this time

PLATE XLIV.

ANCIENT MONOLITH SET UP BY A PRE-MONGOL PEOPLE.

to say that later work on this problem has been very productive from both a geological and archæological standpoint.

There is no object at this point in speculating on the place of man's origin. It is conceded that there is evidence elsewhere of the existence of Pliocene man, and, if the other conditions were as favorable as the climate during the Pliocene and Pleistocene, man may have existed in the Gobi region during the Pleistocene and possibly also during part of the Pliocene. Among the many suggestive thoughts offered by Joseph Barrell (1917) as guiding hypotheses for our explorations in central Asia, his idea about primitive man is especially ingenious. Man's strong padded foot, his relatively long leg and his erect posture, are all distinct departures from an adaptation to life in the trees, and tend, instead, to fit him for running and for tramping long distances; in short, for life on open plains where trees grow in patches along the stream courses, rather than for life in a dense forest. Granting that the more distant ancestors of men lived in trees and in jungles, it seems probable that they would have remained arboreal in an environment of jungle and forest. But in a region where forests were thinning, where open, treeless plains were beginning to appear, and where the climate was changing toward cooler and more arid conditions, it seems probable that arboreal types must adapt themselves to the plains, or become extinct.

Central Asia probably offered just such a combination of opportunity and penalty during Tertiary and Pleistocene times. It had a variable climate swinging from arid to semiarid conditions and therefore was exceptionally favorable to ranging animals which were tending toward the evolution of fleet limbs and long endurance. It also formed the northern borderland of the tropical forest country; and with the changing climatic cycles, the forests must have advanced into central Asia and died out more than once. The growing barrier of the Himalayas and the elevation of the vast interior plateaus profoundly altered living conditions for all the creatures that tried to maintain themselves in the region. If the ancestors of man actually lived there, it seems not unlikely that they must have developed adaptations to life in the open plains and the abruptly upstanding hills, where patches of forest still lingered along the water-courses. It is fair to search the country thoroughly for proof or disproof of the working hypothesis that central Asia is the right locality, and had, during the critical periods, the right environment for the evolution of man.

Pliocene beds are exposed in few places, and it is possible that they may carry important evidence, but their limited development is a distinct handicap. There must have been sediments forming somewhere in adjacent regions while the central Gobi was being eroded. The material carried out of the region, both by streams and by wind, must have lodged somewhere under more favorable conditions, and these deposits of adjacent territory should be much more promising, not only for possible remains of man, but also for the remains of all other forms of late Pliocene and Pleistocene life. It is the hope of the Expedition that in the work of its additional years, for which traverses are projected into adjacent districts, some of these more favorable conditions and the deposits of later time may be discovered.

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In the bibliography, complete works are printed in italics, thus: *The Russian Road to China.* Serial publications are listed in the same category, thus: *Bull. Geol. Soc. Amer.* Reference to special articles in complete works or serial publications are printed in Roman letters and are enclosed in quotation marks, thus: "Migration of Geosynclines." *Bull. Geol. Soc. China*, Vol. III, No. 3–4, pp. 207–349. Peking.

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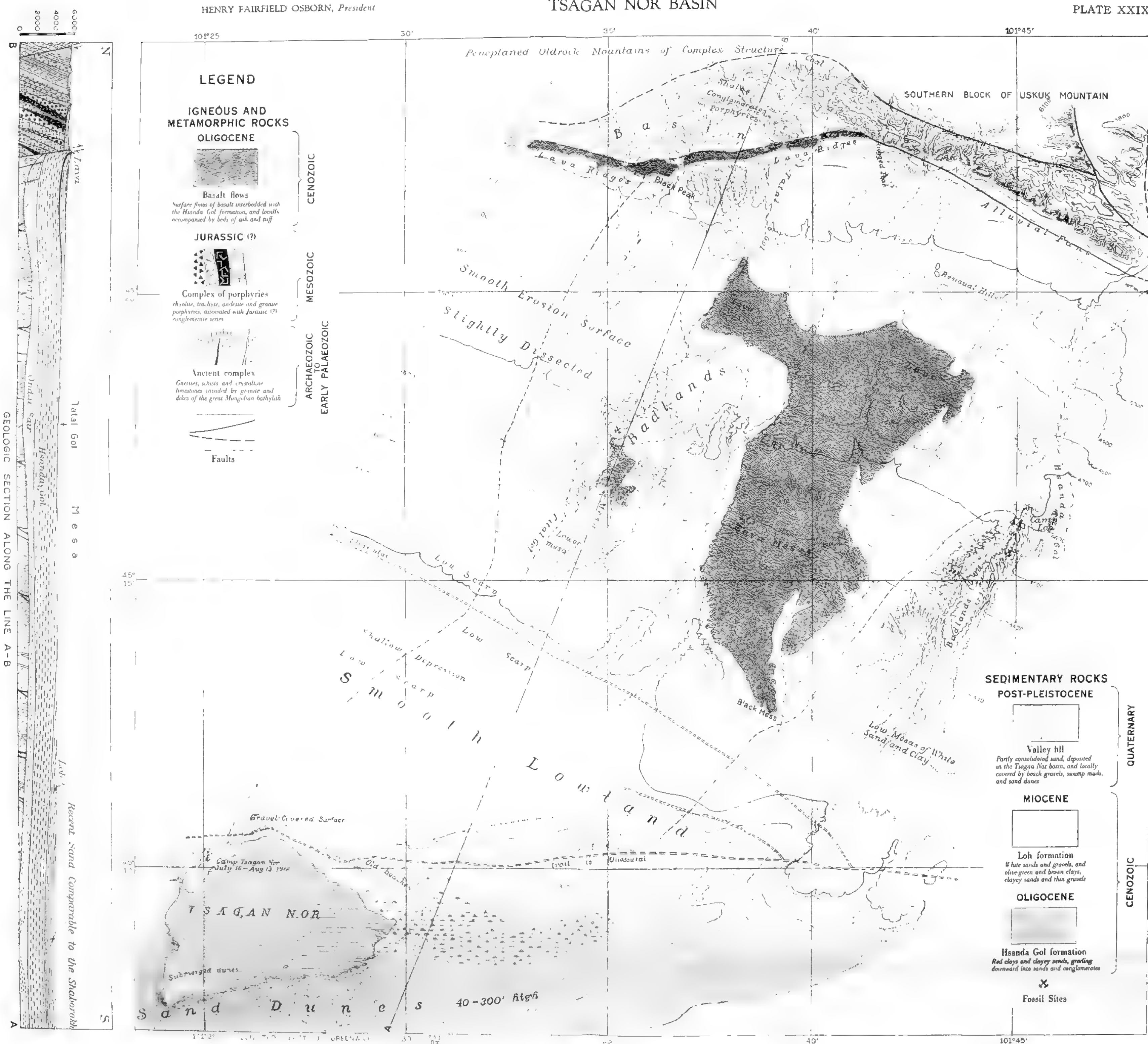
INDEX

Text illustrations are classified in the Index as figures, maps and sections. They are referred to by page number, not by figure number: thus figure 5, on page 47, is entered as 47.

RECONNAISSANCE GEOLOGIC MAP
OF PART OF THE
TSAGAN NOR BASIN

THE AMERICAN MUSEUM OF NATURAL HISTORY
HENRY FAIRFIELD OSBORN, *President*

GEOLOGY OF MONGOLIA
PLATE XXIX



TRUE NORTH
MAGNETIC NORTH

Scale $\frac{1}{100000}$

Miles

Kilometers

Contour Interval, 100 feet

CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922
Datum, Tsagan Nor in 1922
Lake outline, altitude, and position taken from the survey by L. B. Roberts, 1922
Parts of the map, especially the western part between Tsagan Nor and Tatal Gol are sketched with but few located points
Drawn by Erwin J. Raisz

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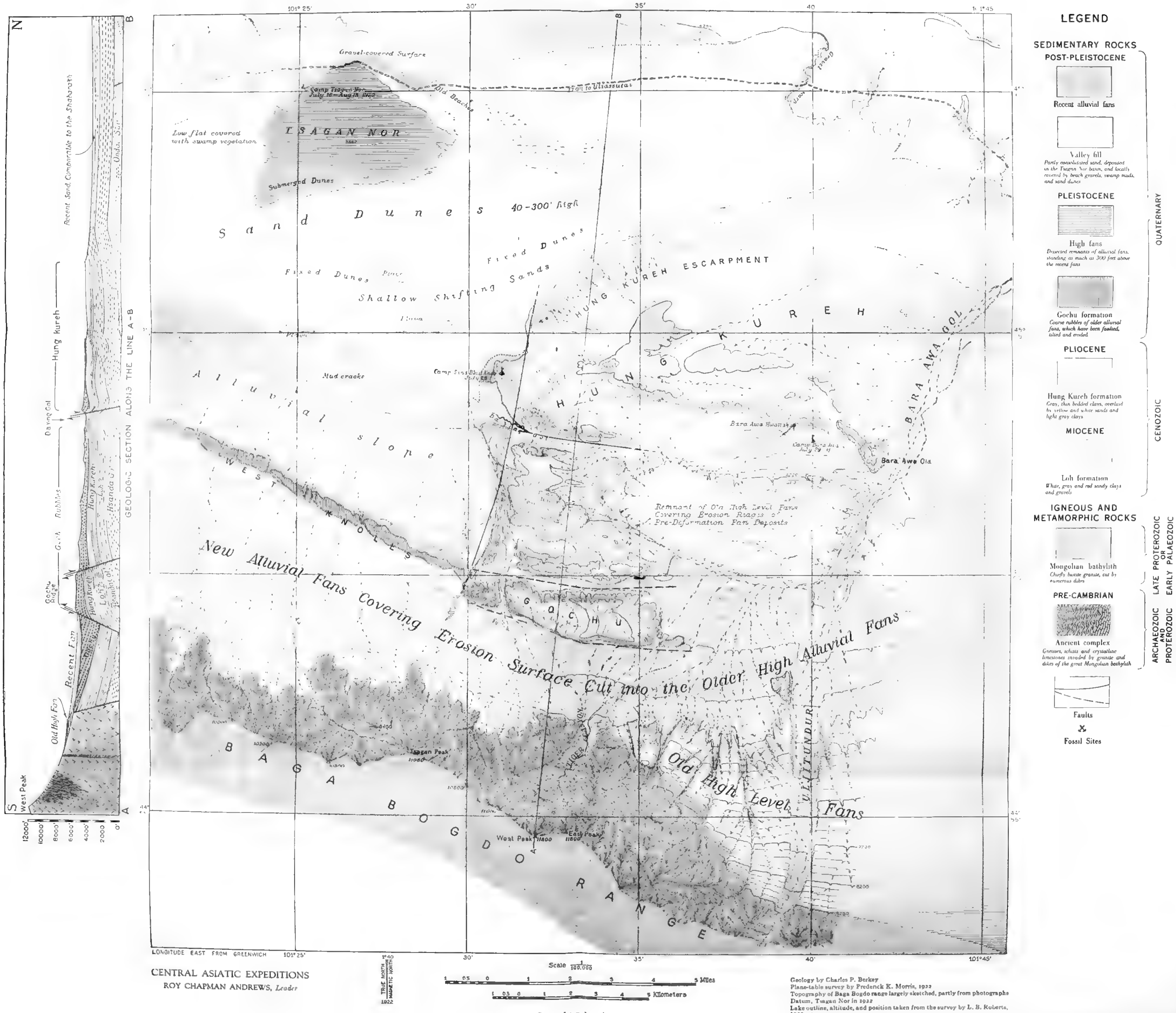
RECONNAISSANCE GEOLOGIC MAP
OF THE
HUNG KUREH AREA

GEOLOGY OF MONGOLIA
PLATE XXX



CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

Scale 1/100,000
Miles
Kilometers
Contour Interval, 100 feet

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922
Topography of Baga Bogdo range largely sketched, partly from photographs
Datum, Tsagan Nor in 1922
Lake outline, altitude, and position taken from the survey by L. B. Roberts, 1925
Drawn by Erwin J. Raisz

RECONNAISSANCE GEOLOGIC MAP
OF THE
HSANDA GOL AREA

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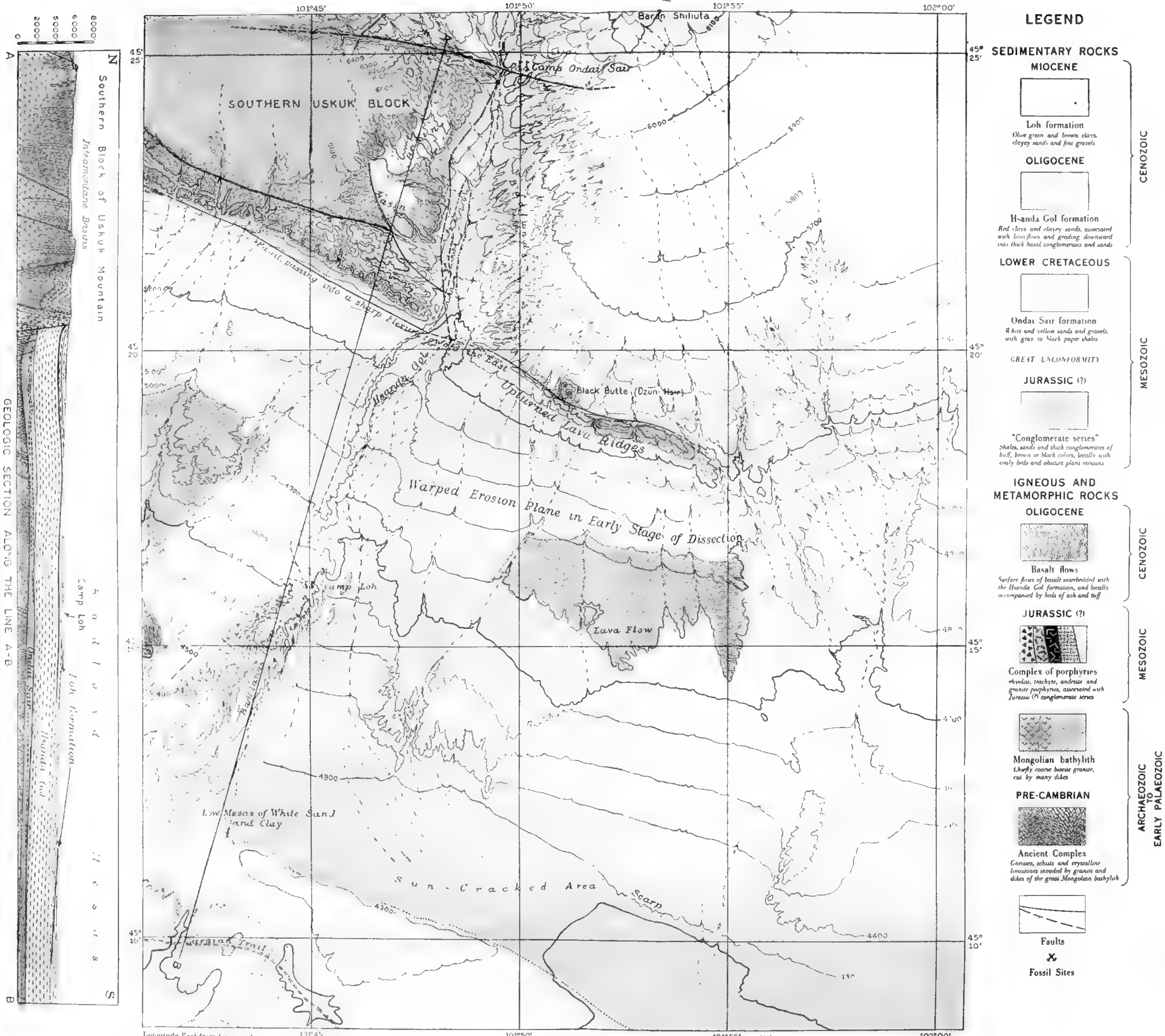
GEOLOGY OF MONGOLIA
PLATE XXVIII



Scale $\frac{1}{100{,}000}$

Miles

Kilometers

Contour Interval, 100 feet

TRUE NORTH MAGNETIC NORTH 1°40' 1922

CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922
Eastern and southern parts of the map sketched with aid of only a few points located by triangulation
Drawn by Erwin J. Raisz

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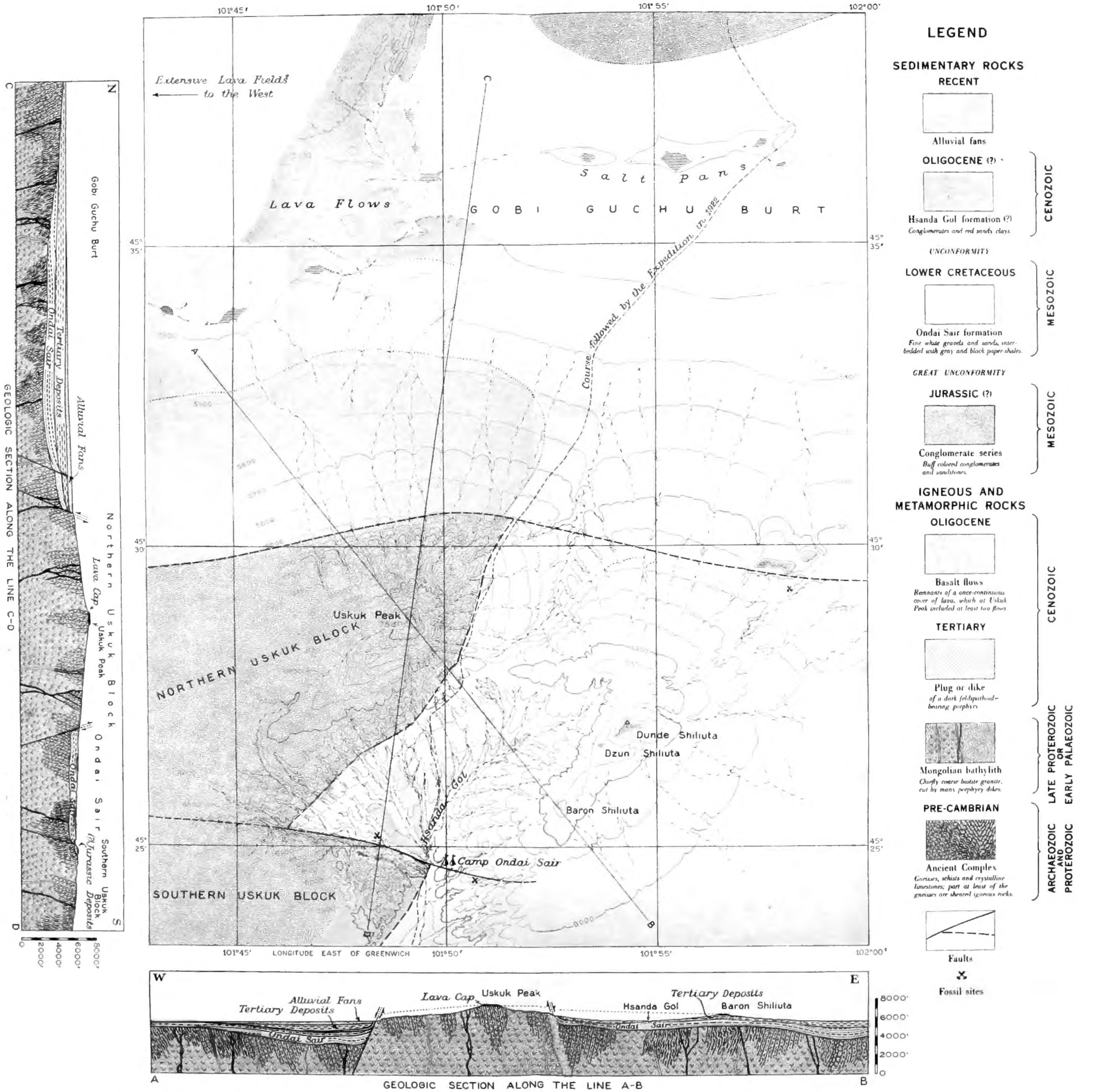
RECONNAISSANCE GEOLOGIC MAP
OF THE
MOUNT USKUK AREA



CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

Scale $\frac{1}{100,000}$

1 0.5 0 1 2 3 4 5 Miles

1 0.5 0 1 2 3 4 5 Kilometers

Contour Interval, 100 feet

1°40′ TRUE NORTH MAGNETIC NORTH 1922

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922
Drawn by Erwin J. Raisz

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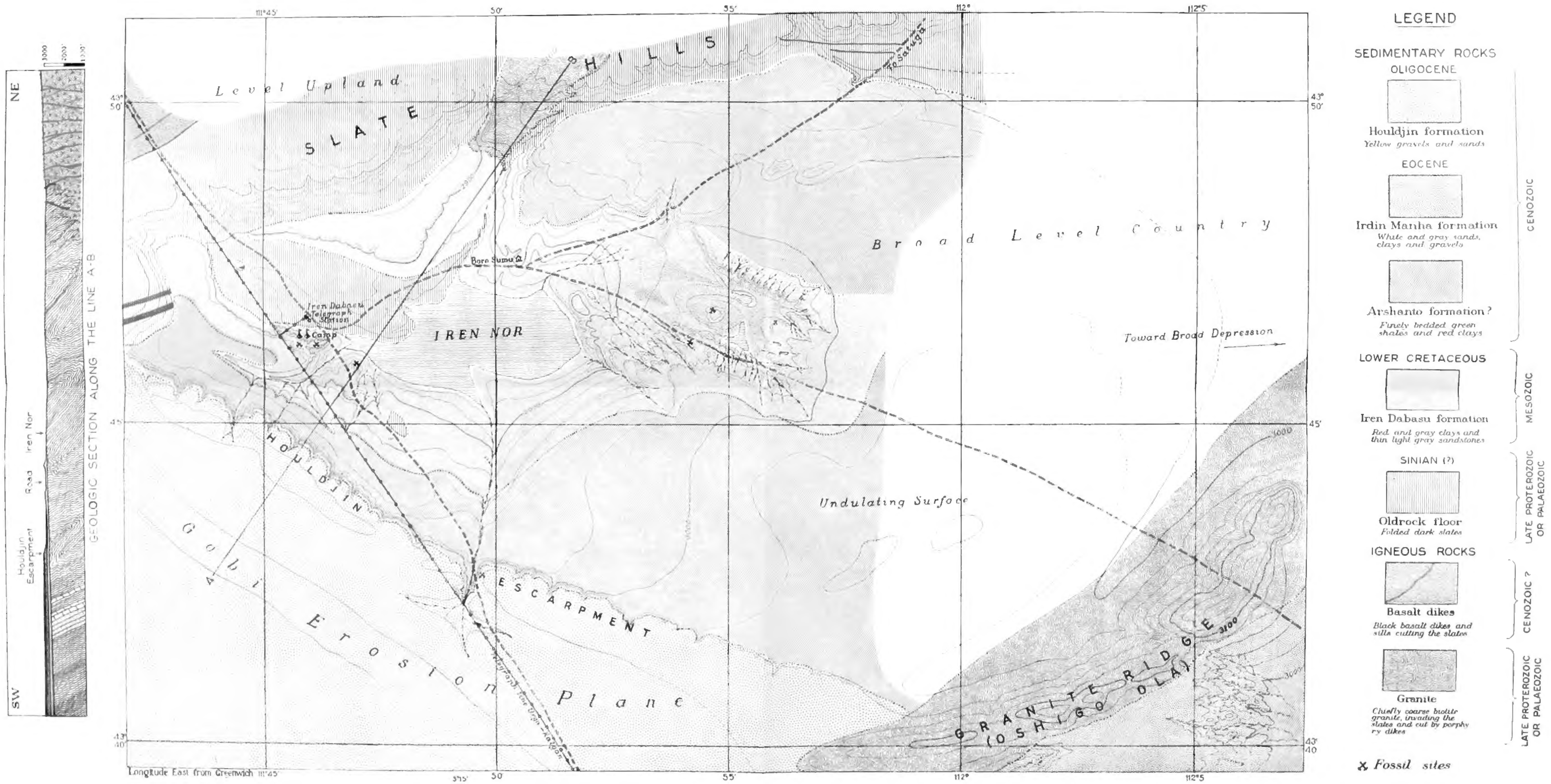
RECONNAISSANCE GEOLOGIC MAP
OF THE
IREN DABASU AREA

GEOLOGY OF MONGOLIA
PLATE XXIII



CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

MAGNETIC NORTH — TRUE NORTH — 3°15' — 1922

Scale $\frac{1}{100000}$

1 0.5 0 1 2 3 4 5 Miles

1 0.5 0 1 2 3 4 5 Kilometers

20 Chiang 0 1 2 3 4 5 Chinese Li

Contour Interval, 20 feet

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922–1923
Drawn by Erwin J. Raisz

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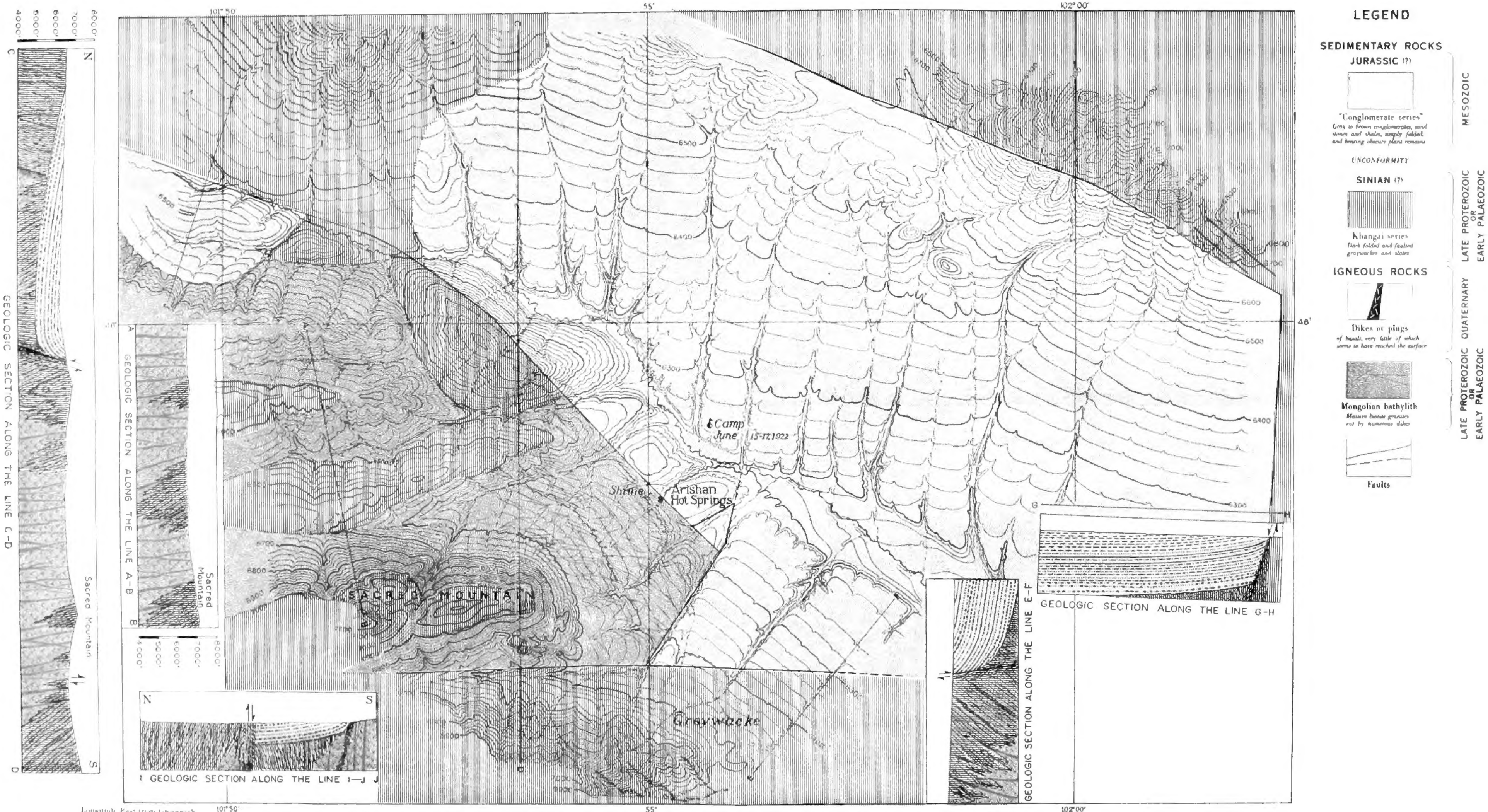
RECONNAISSANCE GEOLOGIC MAP
OF THE
ARISHAN AREA

GEOLOGY OF MONGOLIA
PLATE XXVI



Longitude East from Greenwich

CENTRAL ASIATIC EXPEDITIONS
ROY CHAPMAN ANDREWS, *Leader*

Scale $\frac{1}{50000}$

4 Miles

4 Kilometers

Contour Interval, 20 feet

Geology by Charles P. Berkey
Plane-table survey by Frederick K. Morris, 1922
Western and northeastern portions of the map sketched with the aid of a few points located by intersection
Latitude and longitude only approximate, as position was not determined at this camp
Drawn by Erwin J. Raisz