DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 631

THE YUKON-KOYUKUK REGION ALASKA

BY

HENRY M. EAKIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
20 CENTS PER COPY

CONTENTS.

ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

The information presented in this volume is based on exploration of the Yukon-Koyukuk region, which previous to Mr. Eakin's journey of 1913 was but little known. This journey was undertaken as part of the general plan to carry reconnaissance surveys over the unmapped areas of Alaska as fast as conditions permit.

The funds available for this work did not allow the organization of a large party or the detail of an experienced topographic engineer. Therefore it fell to Mr. Eakin not only to survey the geology but also to construct his own base map. He deserves great credit for having, in a single season, mapped so large an area, and his work has yielded many new data bearing on the larger geologic problems of the Yukon basin.

The economic results of the investigation are largely negative, for but few mineral deposits occur in the region. The only mining has consisted in the small-scale placer operations in the Indian River district. On the other hand, certain intrusive granites which are shown by Mr. Eakin to be the mineralizing agents are rather widely distributed, and therefore the region, in spite of the meager results thus far achieved by the prospectors, should be classed as one in which there is hope of finding auriferous deposits.

Mr. Eakin, in this volume, presents a valuable analysis of the problems relating to the origin of the drainage system of the middle Yukon region. In this analysis he clearly shows that there have been very extensive changes of drainage during Quaternary time. These changes, Mr. Eakin believes, are due to the advance of glaciers from the mountains which bound the central plateau region. While Mr. Eakin's conclusion is worthy of consideration, in the opinion of the writer, it should be regarded as a working hypothesis rather than as a theory that now admits of definite proof.

In view of the importance of these problems, which involve the history of the drainage system of all the central plateau region, it will be well to present briefly the principal facts that seem to be opposed to Mr. Eakin's conclusions. These relate chiefly to the adequacy of the glacial dams to bring about a complete reversal of so extensive a drainage system.

Mr. Eakin holds that the larger rivers of the Yukon-Koyukuk region formerly flowed north, and that the reversal of this drainage direction was caused by a southward-moving ice sheet from the Endicott Mountains. Opposed to this explanation are the observations of Smith,[1] who, in describing the glaciation of the Koyukuk basin, says: "So far as known, glacial ice did not reach the valley of the main river, but the evidence as to the foremost stand of the ice is obscured by the later deposits." It should be added that Maddren's studies in the upper Koyukuk basin[2] led him to believe that glaciation extended from the Endicott Range southward along Koyukuk River to beyond the Arctic Circle. This evidence is interpreted by the writer to indicate that while valley glaciers may have moved far enough south to reach the former northward-flowing rivers described by Mr. Eakin, yet there is much doubt whether these ice masses were of sufficient volume to dam the streams and cause a reversal of drainage 100 miles to the south.

Mr. Eakin holds that the Nowitna, a southerly tributary to the Yukon, formerly flowed southward into the Kuskokwim. This conclusion is based on the assumption that there is a low divide between the Nowitna and Kuskokwim, of which there is not definite proof. Even if, however, the topography of this unsurveyed region is favorable to such an interpretation, there is still question whether the reversal in drainage was due to glacial ice. To reach the locality of the supposed ice dam from the Alaska Range the glacier would have had to be nearly 100 miles in length. The evidence seems to be against so long a glacier in this region. To the northeast the glaciers from the Alaska Range did not even reach across the Tanana Valley,[3] a distance of about 30 miles.

The writer has stated[4] that during their maximum extent the glaciers of the Alaska Range probably reached 30 miles out into the Kuskokwim lowland, which would thus bring their termini far to the south of the locality where Mr. Eakin has postulated an ice dam. Assuming that ice did reach this locality, it would be but the front of a valley glacier, and it is at least a question whether it would be of sufficient magnitude to form an ice dam large enough to cause the extensive reversals of drainage assumed by Mr. Eakin.

---

[1] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 97, 1913.

[2] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, p. 62, 1913.

[3] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, p. 37, 1912.

[4] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 126, 1911.

The third locality where Mr. Eakin believes an ice dam to have existed is on the watershed between middle Porcupine and lower Mackenzie rivers east of the international boundary. This ice barrier is supposed by Mr. Eakin to have turned the ancestors of the present Yukon and Porcupine, so that their waters sought a southerly outlet. Here, indeed, the direct evidence of the former presence of glacial ice is more convincing than at the other localities mentioned. McConnell[1] has shown that during the maximum glaciation the entire lower Mackenzie Valley was probably ice-filled and that the mountains along the Peel River portage show some evidence of glaciation up to 500 feet and possibly to 1,500 feet above the sea. The writer will raise the question, however, whether these phenomena constitute sufficient evidence to justify the hypothesis of an ice barrier that ponded the waters over an area of 50,000 to 100,000 square miles.

Another fact bearing on the problem is the character of the Yukon Valley between the mouth of the Tanana and the Yukon Flats. Here the valley winds in a series of sweeping curves that strongly suggest the incised meanders of an antecedent stream. It is in this stretch of the Yukon that Mr. Eakin locates his former watershed between the waters flowing southwestward to the Kuskokwim and those flowing northeastward to the Mackenzie. The writer[2] has suggested that this part of the Yukon Valley represents incised meanders, inherited of a previous drainage cycle, an explanation that seems to be in accord with the known facts.

The suggestion is offered that the changes of drainage are due not to ice damming but to barriers formed by local warping. Evidence of local deformation of Quaternary deposits has been found in various parts of the Yukon basin.

---

[1] McConnell, R. G., An exploration in the Yukon and Mackenzie basins: Canada Geol. and Nat. Hist. Survey Ann. Rept., new ser., vol. 4, p. 27D, 1890.

[2] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 284, 1906.

THE YUKON-KOYUKUK REGION, ALASKA.

By Henry M. Eakin.

INTRODUCTION.

PURPOSE OF REPORT.

The region in central Alaska lying between Yukon and Koyukuk rivers west of the Yukon Flats has in general been little frequented by prospectors. Owing to the consequent lack of economic interest those parts of the region not immediately accessible from the rivers have long remained geologically unexplored. Interest in the geology of the region, however, had been stimulated by the results of surveys carried on in the adjacent regions on all sides—especially those of the Rampart, Hot Springs, Gold Mountain, and Ruby gold-bearing districts, along the Yukon—and by the more recently reported discoveries of placer gold on the headwaters of Indian and Kanuti rivers and on tributaries of lower Melozitna and Tozitna rivers.

During the summer of 1913 a Geological Survey party in charge of the writer made a rapid reconnaissance through the more inaccessible and geologically unknown parts of the region. The writer had previously visited certain parts of the region and adjacent territory, having accompanied W. W. Atwood in 1907, during his study of the coal-bearing rocks of the Yukon section, and P. S. Smith in 1909 and 1910, when surveys were made west and north of lower Koyukuk River, and having studied more closely the rocks of the Yukon section from Rampart to Kokrines in 1911 and in the vicinity of Ruby in 1912. During 1914 also he spent a few days in making a short traverse into the region northward from Tanana.

Investigations of other parties, described more fully on other pages, have touched certain areas of the Yukon-Koyukuk region, and the purpose of this report is to present the available information from all sources regarding the salient features of the geography, geology, and resources of the region. (See Pls. I and II, in pocket.)

ACKNOWLEDGMENTS.

The writer wishes to express his appreciation of the uniform courtesy of transportation officials and residents of the region who at various times facilitated his work and added to his comfort, often at personal inconvenience, and also of the loyal service rendered dur-

ing the 1913 expedition by J. C. Doyle, H. H. Winter, and C. T. Moore, whose untiring labors made an unusually arduous journey successful. He is also indebted to the numerous investigators whose work has contributed to the subject matter of this report.

FIELD WORK.

The field work of the writer that has contributed chiefly to the following pages was done during the seasons of 1911, 1913, and 1914.

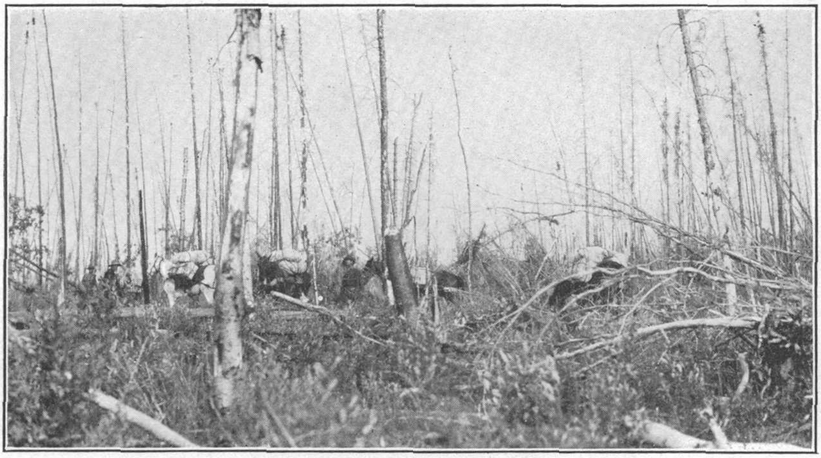
In 1911, after a reconnaissance of the Rampart and Hot Springs districts, a boating trip was made from Rampart to Kokrines, which occupied about a month and the results of which have been published.[1] Several trips for a few miles inland from the river were made, notably at Squaw Creek, near Rampart, at Gold Hill, and at Birches telegraph station.

During the summer of 1913 a reconnaissance was made through the more central part of the region. The party, including C. T. Moore, topographer, J. C. Doyle, packer, and H. H. Winter, cook, landed on the north bank of Yukon River about 15 miles below Fort Hamlin June 19 and got under way the following day. A pack train of five horses carried equipment and sufficient supplies for six weeks. It was planned to carry on topographic work by plane-table triangulation and geologic work, with pace traverses and the topographic work for control.

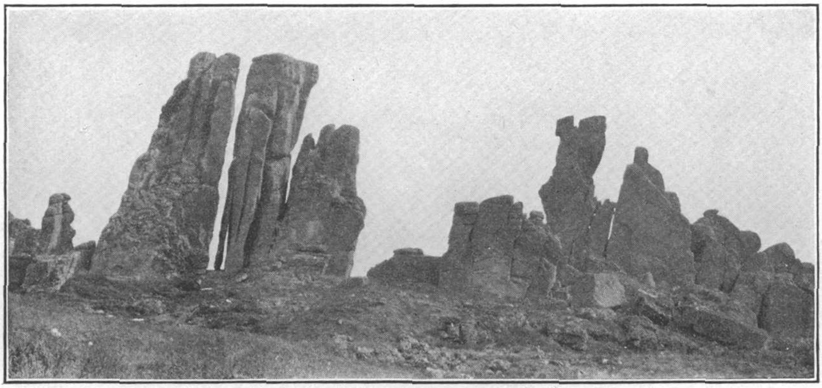
The route of travel lay first around the north and west margins of the Ray River basin to its extreme southwesterly headwaters at the locality of camp 14. (See Pl. II.) Here the camp outfit was left for a few days while the writer and Mr. Doyle, traveling light, made a hasty trip southeastward to the main northeast tributary of Tozitna River, tying in with the previous work on Squaw Creek. On the return to camp 14 several southwesterly tributaries of Ray River were crossed.

From camp 14 the journey was resumed in a general northwesterly direction, first along the Tozitna-Kanuti divide and then around the north margin of the Melozitna basin to the east headwaters of Indian River. A high ridge was followed from this place for a few miles westward to the broad depression where the waters of Indian River and Mentanontli Creek divide. The lowlands were crossed on the Indian River side of the divide, and thence the way led over a group of rugged mountains to the mining camp on upper Indian River and over a well-traveled wagon road westward to Hughes, which was reached July 26. After replenishing supplies from a cache which had been shipped to Hughes the party left the following day, going first southeastward across the Indian River basin to the Melozitna-

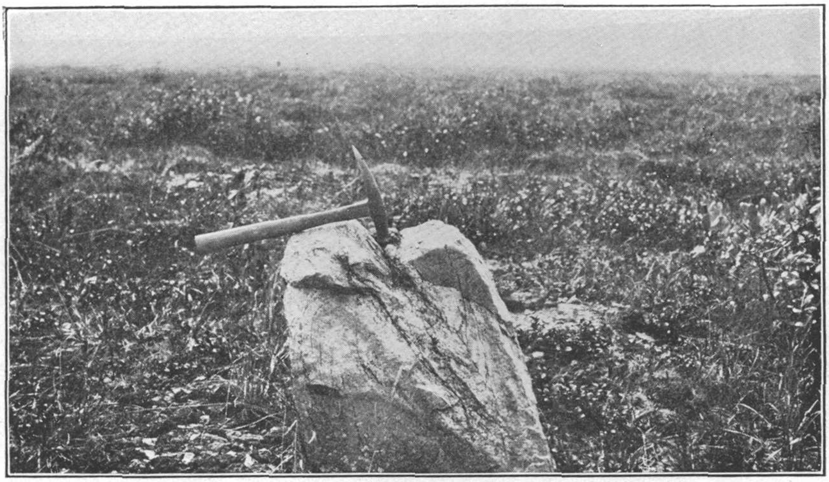
[1] Eakin, H. M., A geologic reconnaissance of part of the Rampart quadrangle, Alaska: U. S. Geol. Survey Bull. 535, pp. 17, 34, 1913.



A. BURNED AND PARTLY FALLEN TIMBER, RAY RIVER BASIN.



B. GRANITE PINNACLES NEAR CAMP 11.



C. CLOSE FOLDING IN GREENSTONE, RAY-DALL DIVIDE.

Koyukuk divide and then southwestward along the high ridges at the west margin of Melozitna basin to the Yukon, which was reached August 24. The writer spent the rest of the season visiting the Ruby mining camps, while his assistants did some additional topographic work for a short distance above Ruby.

During the first half of the season the conditions for work were decidedly unfavorable. Smoke of forest and tundra fires obscured the landscape for weeks together, and much of the time it was impossible to discern objects more than half a mile distant. A few fires were actually encountered, necessitating hurried travel in some places and delay in others. The absence of horse feed in the burned-over forest areas made long forced marches necessary in places, when the energies of the entire party were required to get the outfit through. About 40 miles of trail in all had to be chopped out, work which was especially arduous in the heavy growth on the lowlands and where fallen timber, killed by previous fires, blocked the way. (See Pl. III, *A*.) Plane-table work was impracticable except for two periods of two and five days, when it was attempted with but indifferent results. It was necessary to guide the pack train by compass and to keep the party together much of the time, which hampered the scientific work. As much as possible, however, the course of the traverse was directed to determining the boundaries of the several formations and those actually determined are so indicated on the map (Pl. II, in pocket). The extensions of boundaries beyond the immediate vicinity of the traverse are based on structural laws that are fairly trustworthy. The later part of the season, while the trip was made from Hughes to the Yukon, was more favorable, and plane-table work was carried on for almost the entire distance. Travel was easier and a greater breadth of country was covered.

The pace traverses of the season aggregated about 350 miles. About 2,000 square miles was mapped by plane table, and the topography of additional areas along the traverses was sketched. (See Pl. I, in pocket.) The geologic work covered the same general areas, but the data gathered, taken in connection with work previously done, have a much greater areal significance.

In 1914 a short traverse northward from Tanana to a height of land overlooking the lower part of the Tozitna River basin gave a new insight into the topography and geology of that part of the region.

PREVIOUS INVESTIGATIONS.

The northwestern part of the region, along Koyukuk River, was visited by Schrader[1] in 1899, and the northeastern part, along Dall

[1] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 441–486, 1900.

and Kanuti rivers, by Mendenhall[1] in 1901, and along Dall River by Maddren in 1903.[2] The areas along the Yukon have been discussed by Dall,[3] Russell,[4] Spurr,[5] Collier,[6] Maddren,[7] and others incidentally to general investigations along the Yukon or to the surveys of adjacent regions. The reports of all these men have been freely used in the preparation of the present volume.

GEOGRAPHY.

LOCATION AND EXTENT.

The Yukon-Koyukuk region embraces an area of about 12,000 square miles in central Alaska, lying between Yukon and Koyukuk rivers west of the Yukon Flats. Roughly speaking, it extends from longitude 159° to 157° W. and from latitude 65° N. to the Arctic Circle, although considerable areas within these boundaries are not included between the rivers.

RELIEF.

GENERAL CHARACTER.

The relief of most of the region is low, but locally there are mountainous areas in which elevations rise to 5,000 or 6,000 feet. The predominant type of topography consists of rolling, maturely dissected uplands of moderate elevation. Almost as extensive are broad lowlands that floor the major erosional depressions of the region.

MOUNTAINOUS AREAS.

The largest mountainous area includes about 2,000 square miles in the northeastern part of the region, on the headwaters of Ray, Tozitna, and Kanuti rivers. The ranges occupying this area are generally known as the Ray Mountains. The highest known point is about 6,000 feet above sea level. Numerous peaks rise above an altitude of 5,000 feet and considerable areas stand almost as high.

---

[1] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, 1902.

[2] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, 1913.

[3] Dall, W. H., Exploration in Russian America: Am. Jour. Sci., 2d ser., vol. 45 1868, pp. 97–98; Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, p. 247, 1892.

[4] Russell, I. C., Notes on the surface geology of Alaska: Geol. Soc. America Bull., vol. 1, 1889.

[5] Spurr, J. E., Geology of the Yukon gold district, Alaska, with a chapter on the history and present condition of the district by H. B. Goodrich: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 87–392, 1898.

[6] Collier, A. J., The coal resources of the Yukon, Alaska: U. S. Geol. Survey Bull. 218, 1903.

[7] Maddren, A. G., Placers of the Gold Hill district: U. S. Geol Survey Bull. 379, 1909, pp. 234–237; The Innoko gold-placer district, Alaska, with accounts of the central Kuskokwim Valley and the Ruby Creek and Gold Hill placers: U. S. Geol. Survey Bull. 410, pp. 80–83, 1910.

The topography is extremely rugged for the most part and over extensive areas it is marked by striking pinnacles of granite resembling those in the Colorado "Garden of the Gods." (See Pl. III, *B*.) The valleys generally head in glacial cirques and have characteristic glaciated forms in their headward portions.

Smaller mountainous areas lie between Melozitna River and the Yukon and about the headwaters of Indian River, and one extends from the Melozitna Canyon northwestward for about 25 miles. The elevations within these areas nowhere greatly exceed 4,000 feet and are in general considerably less. Their features, however, have a bold mountainous aspect owing to the low relief of the adjacent country. Topographic forms due to glaciation are developed only locally and are not so extensive as in the Ray Mountains.

Formerly the name "Yukon Hills" was applied generally to the uplands between Yukon and Koyukuk rivers. The uplands are separated by broad depressions into several topographically distinct sections. Since the use of a general designation implies a much closer similarity and broader continuity of topographic aspects than really exist in the uplands of this region there can be but little advantage in its continuance. The names of the distinct and widely separated mountain groups form a useful part of geographic nomenclature and three of these are here published, probably for the first time—the Ray Mountains, whose area has been indicated, the Kokrine Mountains, lying between Melozitna and Yukon rivers, and the Indian Mountains, a small group in which Indian River heads. These groups have geologic as well as topographic distinction, being developed in areas of igneous intrusion and metamorphism, and the application of separate names to them is in keeping with the general usage for numerous similar mountain groups of the Yukon basin.

There is an unusually striking development of high-level terraces and flat summits and passes in the mountains of the region—features of a type that is widely distributed in interior Alaska but whose origin has generally been regarded as obscure. Their ideal development and consistent relation to definite geologic conditions in the Yukon-Koyukuk region have thrown considerable light on the laws of their occurrence, which are discussed under the heading "Altiplanation terraces" (p. 78).

NONMOUNTAINOUS UPLANDS.

The nonmountainous uplands of the region are far more extensive than the mountainous areas, being generally developed on the Mesozoic sedimentary rocks that occupy the western part of the region and on the Paleozoic schists that cover large areas in the eastern part.

The surface of the Mesozoic areas generally consists of fairly persistent, irregularly cusped ridges and open, steep-headed valleys. In places the dependence of topographic forms on geologic structure is evident. Extensive alluvial deposition in late geologic time has reduced the general prominence of the ridges where they extend out between the broader valleys, and in some places those of lower elevation have been almost completely buried.

In the areas of Paleozoic schist the characteristic topographic forms are persistent, broad, smooth-topped ridges of flowing contour that show little evidence of structural control. The lower slopes merge into the broad lowlands of the valleys without the abrupt transition noted in the Mesozoic areas. A more rugged topography, however, is generally developed on the Paleozoic greenstones and limestones at similar elevations.

LOWLAND PLAINS.

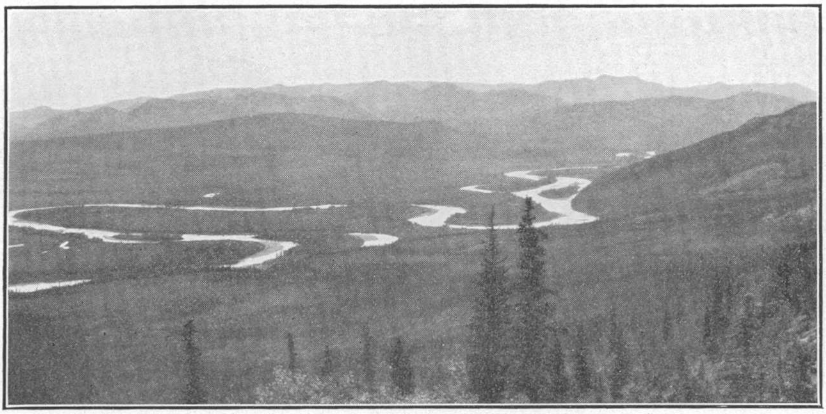
Lowland plains form a striking feature of the region. They occupy large areas bordering Koyukuk River and extend broadly into the basins of its larger tributaries. The Yukon Flats have a westward continuation in the basins of Dall and Ray rivers. A similar feature sweeps across the center of the region, flooring the middle sections of the Tozitna and Melozitna basins. The lowlands are constructional features, resulting from alluviation in late geologic time that was largely incident to the glacial damming of old drainage lines and the subsequent readjustment of gradients in rearranged drainage systems. They include the flood plains of the present streams and the terraced or sloping surfaces of silt and gravel deposits at slightly greater elevations.

DRAINAGE.

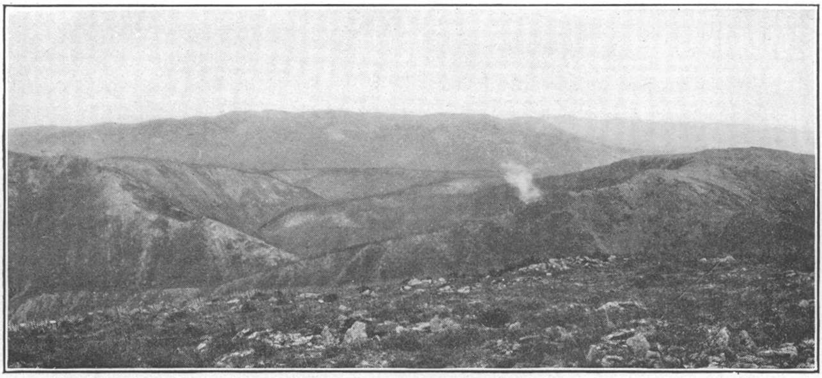
The region is drained entirely by tributaries of Yukon and Koyukuk rivers. The arrangement and relative size of the streams are shown on the map (Pl. I, in pocket). The drainage has many anomalous features that have an important bearing on the morphology of the region. These include lowland divides, canyons, and back hand drainage.

LOWLAND DIVIDES.

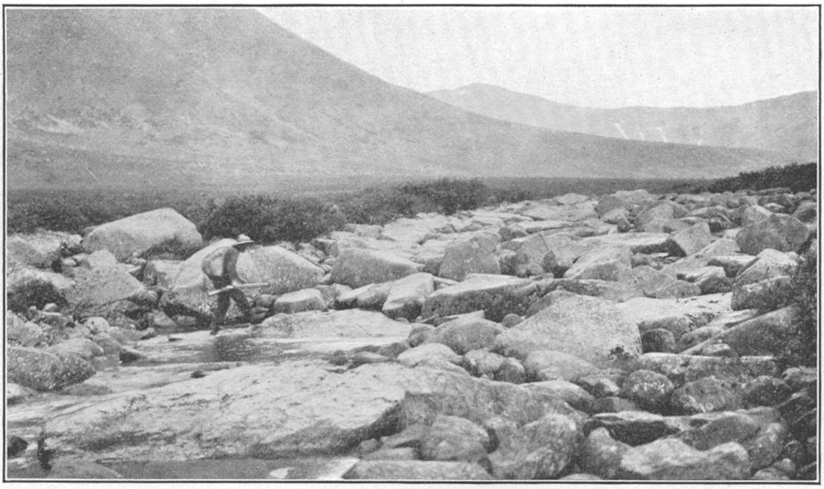
The most striking lowland divides are those between Tozitna and Melozitna rivers, Melozitna and Kanuti rivers, and Indian and Mentanontli rivers. In each place the lowlands of both basins are continuous across an indefinite, swampy, lake-dotted divide whose elevation is far less than that of the rims of canyons on the lower courses of the same streams. Similar divides in alluvial areas are to be found between Dall River and a lower tributary of the Yukon, between Kanuti River and one of its large southern tributaries, and possibly in other localities that have not been investigated.



A. MELOZITNA VALLEY, 30 MILES FROM THE YUKON.



B. MELOZITNA CANYON, 5 MILES FROM THE YUKON.



C. GLACIATED VALLEY, SOUTHWESTERN HEADWATER OF RAY RIVER.

CANYONS.

In their lower sections Indian, Melozitna, and Tozitna rivers flow in canyons or constricted valleys that present a strong contrast to the broad, flat-bottomed depressions occupied by the more headward sections of the same streams. No structural or lithologic difference in the country rock of the two sections is evident. The different aspects of the upper and lower sections of the valleys is evidently due to a difference in age, the rivers having followed their courses through the constricted reaches for a comparatively short period of time. Plate IV, *A* and *B*, illustrates these contrasting portions of the Melozitna.

The Yukon also passes through a number of gorges between the Yukon Flats and the Tanana, and its valley is notably constricted at the mouth of Melozitna River. The first gorge begins at the lower end of the flats and extends for about 15 miles. Below it for a few miles is a broad opening through the hills to the right, into a lowland that is continuous with the flats above. The second gorge begins at the mouth of Ray River and extends for about 20 miles to the mouth of Hess Creek. Below this the valley is open and fairly broad for about 40 miles to the upper end of the Lower Ramparts, which consist of three distinct gorges with an aggregate length of 15 miles. Below the mouth of the Tanana a great lowland borders the river on the south for over 100 miles, to the vicinity of Melozitna River, where uplands appear on the left bank, narrowing the valley to a width of a few miles. This constriction would also have had a gorge-like aspect had it not been for the influence of the Melozitna delta, which has caused the Yukon to shift steadily southward, thus widening the valley.

In the constricted sections of the Yukon Valley several minor tributaries that head in the adjacent lowlands have sharp gorges near their mouths, where they traverse narrow ranges of hills.

BACK HAND DRAINAGE.

Back hand drainage, in which the general course of tributaries on both sides is opposite to that of the trunk stream, owing to its reversal (see p. 70), is strikingly developed above the canyons of Indian, Melozitna, and Tozitna rivers. This abnormal condition extends for only a little way along Indian and Tozitna rivers, but in the Melozitna basin it extends for almost the entire length of the major stream.

CLIMATE.

The climate of the Yukon-Koyukuk region is the same that prevails over a great section of interior Alaska. The winters are long and cold; the summers are short and comparatively warm. Precipitation is scant and under more temperate conditions the region would be semiarid. Owing to the generally frozen condition of the subsoil, which prevents loss by seepage, the surface is as a rule well watered through most of the year.

The following table gives the recorded precipitation at Rampart for the years 1906 to 1910, inclusive:

Monthly precipitation, in inches, at Rampart, 1906–1910.[a]

[Rainfall or melted snow is given in the first line; snowfall in the second line.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1906	0.63	0.08	0.17	0.04	0.40	0.15	1.86	2.40	0.59	0.61	0.95	0.33	8.21
	7.2	2.0	1.8	.5	......	......	......	......	......	......	10.2	3.5	25.2
1907	1.17	.44	1.17	.02	.44	1.64	2.29	3.38	2.52	.65	.55	1.26	15.53
	12.0	4.5	12.8	2.5	......	......	......	......	......	......	6.3	......	......
1908	1.08	.52	.81	.58	.82	1.38	1.13	.46	1.56	.39	.73	1.14	10.60
	11.5	6.9	8.1	......	......	......	......	......	......	5.1	3.6	16.8	52.0
1909	.09	.10	.37	.51	1.04	.85	2.01	1.41	.36	1.14	.35	1.99	10.22
	1.4	1.2	6.2	5.6	......	......	......	......	1.5	14.4	3.6	20.2	54.1
1910	.84	.08	.36	.07	.20	.98	.71	.62	.43	.45	.26	.32	5.32
	11.1	.8	4.7	1.0	......	......	......	......	......	6.0	3.5	5.0	32.1

[a] Excerpt from table by C. E. Ellsworth (Water supply of the Yukon-Tanana region: U. S. Geol. Survey Bull. 480, pp. 176–177, 1911).

The rainfall is probably a little greater in the western part of the region than in the eastern part.

The average temperatures of interior Alaska are summarized by Brooks[1] as follows: "The average winter temperature in the province is 5° to 10°, with a minimum of —65° to —76°; for the summer months of June, July, and August the mean is 50° to 60° and the recorded maximum 90°." A later record gives a maximum temperature of 92° on July 27, 1910, at Rampart.[2]

Concerning those phases of climate that affect transportation and mining in the interior provinces of Alaska, Brooks[1] says:

Ice usually begins to run on the Yukon between the first and middle of October, but the delta closes to navigation one or two weeks earlier. In the spring the ice breaks at the mouth of the Tanana about May 10 to 15. So far as the records show, the Tanana breaks a little sooner in the spring and closes a little later in the fall than the Yukon.

The sluicing season in the Fairbanks district usually extends from about May 10 to the middle or end of September. There are records of creeks opening as early as the middle of April, and in 1907 most of the waterways remained open until the end of October.

Except on some of the creeks where the gravels are permeated by circulating ground waters and near hot springs, the ground below a slight depth is permanently frozen in places to depths of 130 feet or more. Where snow accumulates in unusual amounts banks may

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 199, 1911.

[2] Gasser, G. W., Alaska Agr. Exper. Sta. Ann. Rept. for 1910, p. 44.

persist until late in summer or even throughout the season. Elsewhere the ground is generally clear of snow early in May.

Summer climate is a critical factor in determining the agricultural possibilities of a country. The length of the growing season in this region is indicated by the following records made at the United States Agricultural Experiment Station at Rampart:

Length of growing season at Rampart.

Year.	Last spring frost.		First autumn frost.		Days between frosts.
	Date.	Temperature (° F.).	Date.	Temperature (° F.).	
1906	May 20	23	Aug. 25	25	96
1907	May 21	25	Sept. 6	24	107
1908	May 19	30	Aug. 31	29	103
1909	May 29	30	Aug. 24	27	86
1910	May 28	28	Aug. 21	27	84

VEGETATION.

The timber line in the region is about 2,000 feet above sea level, though locally, in protected valleys, trees grow at slightly higher elevations. In the mountainous areas timber grows only in the valleys and on the lower slopes. In the Ray Mountains the valleys are devoid of timber for distances of 5 to 10 miles from their heads. There are large areas in the Melozitna basin below timber line that apparently have never been forested. Figure 1 illustrates the general distribution of timber in the region.

The principal species growing in the region are the spruce and birch. A few scattered tamaracks grow in places, and willows and alders thrive along watercourses and about timber line. Except in favored situations along the banks of streams and at the heads of valleys, the trees are small, generally measuring less than 1 foot in diameter. In some places trees 2 feet or more in diameter can be found, but the areas that support such growth are very small.

Forest fires have swept over large tracts in recent years, and in places repeated burnings have cleared the land completely. Probably half the area between Yukon and Koyukuk rivers was burned over in 1913. However, sufficient timber for the ordinary uses of prospectors remains in almost any part of the region that lies below timber line.

Grasses of several varieties are widely distributed. Redtop is probably the most valuable species for forage. Under primeval conditions it was to be found chiefly along the well-drained banks of streams and about timber line, especially at the heads of valleys. It is one of the first plants to appear in burned-over areas, and in the eastern part of the region, where forest fires have cleared large tracts, there are now luxuriant redtop meadows. It thrives especially

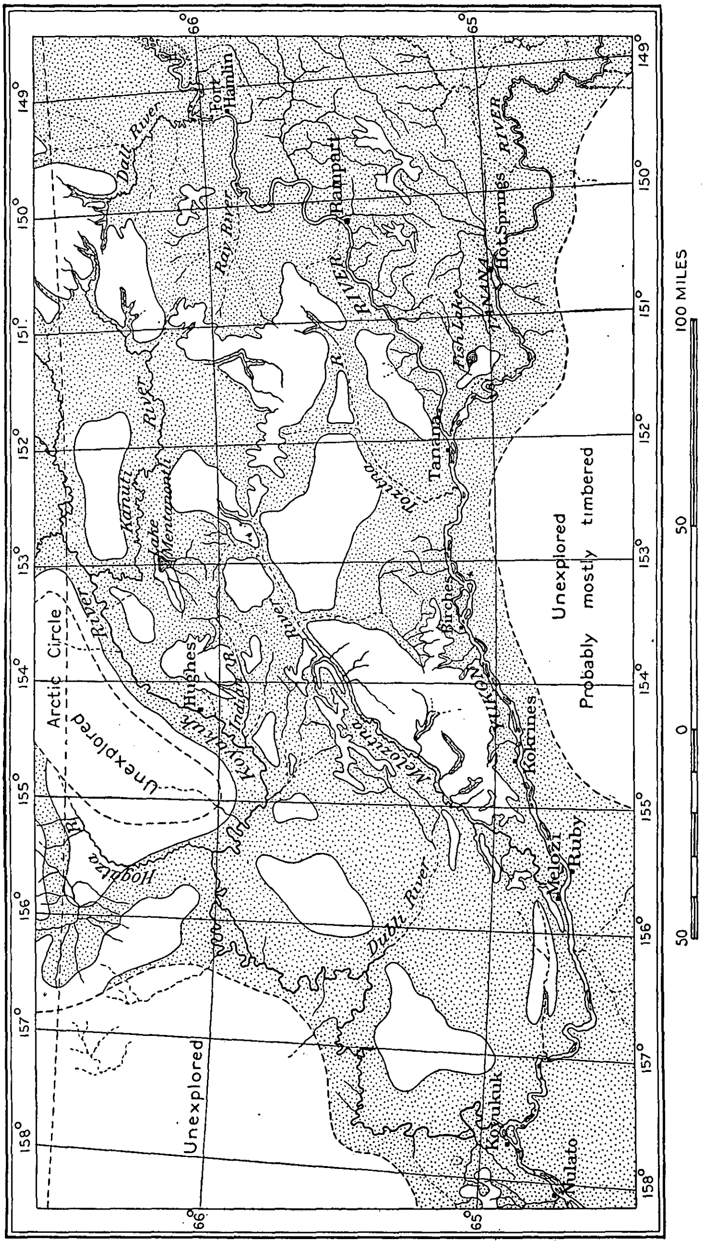


FIGURE 1.—Map showing distribution of timber in the Yukon-Koyukuk and adjacent regions.

well on the silt lands, favoring southerly slopes, where enormous areas of natural growth capable of producing hay of good quality are to be found.

In the western part of the region, which has been more recently burned over, there are no natural meadows except along some of the streams. The only available forage at higher elevations is the redtop at the heads of valleys or other less valuable grasses and sedges on the high passes and upland tundras.

Arctic mosses are generally prevalent over the region. The sphagnum varieties thrive in the sparsely timbered areas and wherever moisture is abundant. The dryer upland areas above timber line are favored by the reindeer mosses or lichens. In much of the area of the Ray Mountains reindeer moss is abundant, and the general conditions are apparently suited for reindeer culture to an unusual degree.

A great number of edible species of berries are native to the region, among which may be mentioned the ever-present blueberries, high and low bush cranberries, currants, and red raspberries. Other species are also to be found, and altogether the natural fruits of the region in their season offer a pleasing and generally abundant addition to the sojourner's ration.

ANIMAL LIFE.

Game is generally abundant in the parts of the region not recently burned. Moose, caribou, and bear were encountered in considerable numbers by the Survey party. Moose are especially plentiful in the Ray River basin and on the adjacent headwaters of Kanuti River. Caribou find attractive pasturage in the uplands of the Ray Mountains and also west of the upper Melozitna. The number of native hunters' caches seen about the headwaters of Ray River also indicate that this is a favorable hunting ground.

Fox, lynx, marten, squirrel, and ermine are chief among the fur-bearing animals. Considerable trapping is done in the regions nearer the Yukon, and in places these animals have been almost exterminated. Foxes are numerous farther inland, and about half of these seen were either silver-gray or "cross" foxes.

Small game and fish were to be had in plenty in all parts of the region. Rock and willow ptarmigan are the most abundant of the resident game birds, the former in the uplands and the latter in the open untimbered valleys at lower elevations. Apparently the willow ptarmigan find the southerly headwaters of Kanuti River an especially favorable breeding ground, for they were to be seen there in countless numbers.

Few grouse were seen along the route followed in 1913, but they are known to be plentiful in the more wooded regions along the larger streams. Among the more common upland birds are species of curlew, plover, and snipe that nest above timber line.

Geese, ducks, cranes, and other waterfowl in large numbers breed in the great lowlands of the region. In the journey along the divide westward from the Ray Mountains, when the landscape was obscured by smoke, the constant clamor of these birds indicated the nearness of the lowlands on the south.

The mountain streams are well stocked with brook trout and grayling, and the latter are abundant also in the lower and larger streams. Salmon run up all the larger streams annually and support a considerable industry along the Yukon, where they are taken as food for both man and beast.

POPULATION.

The population of the region is chiefly localized in settlements on the banks of Yukon and Koyukuk rivers. The white settlements include Rampart (population in 1913 about 50), Tanana (300), and Ruby (1,000), on Yukon River, and Hughes (75), on Koyukuk River. Minor settlements along the rivers, including telegraph stations, road houses, and the like, have a total population of about 50 individuals. About a score of prospectors spend more or less time in the interior of the region.

The natives in this region number about 300. They live in camps and villages on the banks of Yukon and Koyukuk rivers, usually near the mouths of the larger tributary streams. The two largest settlements are probably those near Rampart and Tanana.

COMMUNICATION.

Steamboats ply on the Yukon and Koyukuk during the open season and furnish a ready means of reaching the borders of the region. The larger tributaries of these rivers are generally navigable for poling boats for considerable distances, but much of the region is inaccessible in this manner. The Melozitna Canyon is considered impassable for craft of any sort. Above the canyon this stream is ideal for poling boats and furnishes a possible route through a large territory. Very little boating is actually done on the smaller streams, inland travel being confined mostly to the winter, when dogs and sleds can be used.

Mail service on a weekly schedule is maintained along the Yukon in summer and at longer intervals along the Koyukuk. In winter the mail is carried by dog sledge, the Koyukuk route leading from Tanana across the Tozitna and upper Melozitna basins to the river above the mouth of the Kanuti. The winter service is said to be generally more regular and satisfactory than the summer service. The Government telegraph is available at all the important Yukon settlements.

INDUSTRIES.

The industries pursued by the inhabitants of this region are numerous, but all are related more or less directly to mining, transportation, and the Government military and signal service. Considerable revenue is derived from the salmon taken from the Yukon and dried for dog feed. Large contracts for this product are filled annually for the military post and mail contractors. Large quantities of cordwood from local sources are used by steamboats and in the settlements and mining camps. Lumber for local use is sawed in the larger Yukon settlements, and many persons find employment in supplying saw logs to the mills. A little gardening and trucking is done, and at Rampart an agricultural experiment station is maintained under Government auspices. Here a great variety of products have been grown successfully, a fact which suggests the possibility of expanding the agricultural industry to meet the demands of a much greater population for vegetable and root products, hay, certain grains, and dairy products.

DESCRIPTIVE GEOLOGY.

GENERAL FEATURES.

The areal distribution of the major geologic units of the Yukon-Koyukuk region is indicated on the map (Pl. II, in pocket). The geologic boundaries within the areas that are mapped topographically have been generally determined by actual observation. The extensions of boundaries beyond these areas are hypothetical, being based on general geologic structure and relations observed within the better-known areas. Boundaries have been extended beyond the field of observation only where a fair degree of accuracy seemed assured.

The boundaries of the Quaternary formations indicate only the general character of their distribution and not their absolute margins, which could be delineated only by a far greater amount of work than is possible in a hasty reconnaissance or is merited by their importance. It is intended only to show approximately the width of the present flood plains and the line of demarcation between the more general alluvial deposits and the talus deposits of the upland slopes which are not indicated on the map. The general guidance of topographic forms has been followed, and it is obvious that where these deposits are not expressed topographically error in detail must occur.

A broad zone lying along the Yukon upstream from Ruby is occupied predominantly by metamorphic rocks. The central part of this zone is a metamorphic complex of schists, limestones, quartzites, and greenstones whose structural and areal relations are too intricate and obscure to permit subdivision, except on the basis of much more detailed surveys than those of the present investigation. The time range represented by the complex and the relative abundance of its different members are only generally understood. It undobutedly comprises a very great aggregate thickness of sedimentary rocks, besides bedded and intrusive igneous rocks. The distinctive characteristic of the complex is the uniformly intense metamorphism of all its members. Its general facies is similar to that of the early Paleozoic and possibly older metamorphic rocks of other sections of the Yukon basin.

Farther north, in the latitude of the Ray Mountains, the metamorphic complex is flanked on both the east and the west by greenstones, which occupy large areas almost exclusively. Locally the greenstones have developed a schistose structure, but on the whole they are much less altered and of younger appearance than the members of the metamorphic complex.

In the area extending westward from Melozitna River to the Koyukuk the predominant rocks belong to a great sedimentary series, tentatively correlated with the Cretaceous sedimentary rocks west of Nulato.[1] These rocks appear also locally east of Melozitna River, but without intervening areas of older rocks. As in the Cretaceous series west of Nulato, the basal member is a massive conglomerate. Higher in the series the rocks are finer grained. The prevailing type of formation over large areas consists of alternating thin-bedded sandstones and shales. More massive beds of sandstone and pebbly shales are characteristic of the lower part of the series. In contrast with the older rocks the Cretaceous series has a fairly simple structure and is unaltered except near granitic intrusives, where strong igneous metamorphism is evident.

Between the metamorphic complex on the east and the Cretaceous rocks on the west is a large area in which the rocks are predominantly igneous, being for the most part granitic intrusives and their metamorphic equivalents. These rocks will be referred to as the older granites, in distinction from the younger granites that cut the Cretaceous beds. The older granites are characterized by the high alteration of some of their members, which, though they were plainly granitic intrusives originally, are now augen gneiss and sericite schist. The metamorphism of some of these members is comparable to that of the metamorphic complex, and this seems to imply a much greater age than that of the post-Cretaceous unsheared granites west of the Melozitna. However, these granites and the unsheared members of the older granites may be little, if at all, different in age and therefore the same symbol is used on the map for all the granitic

[1] Smith, P. S., and Eakin, H. M., A geologic reconnaissance of southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, pp. 54–60, 1911.

areas except in places where the altered phases are distinguished. Not all the areas of altered granite have been indicated, and considerable amounts of these rocks between Melozitna and Tozitna rivers are probably included under the general granite symbol.

The younger granites west of the Melozitna are clearly of post-Cretaceous age. Only the areas actually seen are represented on the map, but there are probably a number of other occurrences in the Cretaceous areas that can be located only by more extensive surveys, for these rocks do not have the special topographic prominence usually to be expected of granitic intrusives in general sedimentary areas.

Tertiary sedimentary rocks occupy small areas on the Yukon, on Ray River, and possibly in other parts of the region. They are generally situated low in the erosional depressions, and their extent beyond the actual outcrops is obscured by the younger alluvial deposits. These rocks may, therefore, have a considerably greater areal extent than it has been possible to determine.

Quaternary deposits mantle the older rocks over wide areas in all sections of the region. The most extensive of these deposits is the alluvium of the lowland plains. At higher elevations are terrace deposits of gravel and silt, and locally the mountainous areas contain considerable bodies of material deposited by valley glaciers. Much of the material of the terrace and alluvial deposits may be glacial outwash.

METAMORPHIC COMPLEX.

DISTRIBUTION.

The rocks of the metamorphic complex crop out at intervals along the Yukon from Ruby nearly to Rampart and, except for areas of the older granites, are probably continuous to the northeast in a broad belt that extends beyond the region here considered into the headwater regions of Dall, Chandalar, and Koyukuk rivers.[1] South of the Yukon similar rocks occupy much of the Ruby district[2] and occur in the Rampart district along the Yukon-Tanana divide.[3] In the Yukon-Koyukuk region the actual extent of these rocks is much greater than is indicated on the map (Pl. II, in pocket). They probably immediately underlie the Quaternary deposits over the greater parts of the Ray and Tozitna river basins, besides forming most of the unmapped uplands drained by these streams. They also occur extensively in the uplands drained by the southeasterly tribu-

[1] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pl. 5, 1913. Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, pp. 31–32, 1902.

[2] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, pp. 20–22, 1914.

[3] Eakin, H. M., A geologic reconnaissance of a part of the Rampart quadrangle, Alaska: U. S. Geol. Survey Bull. 535, pp. 16–17, 1913.

taries of Kanuti River and the easterly tributaries of the upper Melozitna.

LITHOLOGY.

The rocks of the metamorphic complex present many different aspects. In places they are predominantly derived from sedimentary formations; elsewhere the metamorphic equivalents of igneous rocks prevail. The original sedimentary rocks of some sections were of clastic types; those of others were calcareous. Among the igneous derivatives both intrusive and effusive types can be recognized, ranging in composition from ultrabasic to persilicic. In addition there are many rock types whose original character is entirely obscured, the metamorphism, though everywhere intense, being more pronounced in some members than in others.

The rocks of the metamorphic complex, except the purer limestones, have developed strong secondary structure, ranging in complexity from a simple slaty cleavage with close parallel foliation to intensely crenulated or crumpled schistosity with intricately intersecting cleavage planes. True slates rarely occur, and practically all these rocks are to be classed as schists. The purer limestones are marmarized, and although they show a pronounced banding, due to flowage, they have no structure comparable with that of the schists. They are true marbles for the most part, and their original structure is rarely evident.

The schists vary in composition according to the original type of rock from which they were derived and the character of their alteration. The clastic sediments are represented by schistose quartzites and quartzitic, quartz-mica, and graphitic schists. Garnetiferous schists are developed along the margins of some of the limestone areas and in other situations and represent the more calcareous phases of clastic sediments. Basic volcanic rocks have produced dark-colored amphibolite schists, and the more acidic intrusive rocks are represented by augen gneisses and feldspathic and sericitic schists.

Other schists of uncertain origin cover broad areas in parts of the region. The more common of these is a fine even-grained biotite schist having a fine slaty lamination. Less common are dark aphanitic schists in which the foliation is broadly outlined by fine quartz laminæ. In some of these that are richer in quartz the closely spaced quartz laminæ make up the greater part of the rock. Locally near the granitic intrusives a great deal of igneous metamorphism has taken place, producing nondescript schists and granular rocks of types not found in other situations. Their composition has evidently been strongly affected by the intrusions, and although they are now quite distinct, they may be the stratigraphic equivalents of some of the more common types of schists in the adjacent areas.

LOCAL FEATURES.

RAY-DALL DIVIDE.

The schists of the Ray-Dall divide are chiefly dark amphibolitic rocks, probably developed from basic volcanic effusives. A few outcrops of quartz-biotite schist occur, but they are evidently of minor areal extent. Granitic intrusives occupy considerable areas along the divide, and near their margins the schists have in places a more granular texture and a lighter color. Quartzose schists in this situation have evidently derived much of their material from the intrusive magmas.

RAY-KANUTI DIVIDE.

The predominant rocks of the Ray-Kanuti divide are fine, even-grained biotite schists that break with a straight, slaty cleavage. Greenstone schists and other quartz-mica schists occur in subordinate amounts. A white, silvery quartz-sericite schist is associated with the darker varieties in narrow bands which suggest that they may represent altered granitic dikes. Nearer the granite areas the sericite schists are more prominent, and in places they contain feldspar augen and apparently grade into the augen gneiss varieties of the granitic intrusives. The quartz-biotite schists hold their prominence southeastward to the Ray-Tozitna divide and westward to the Kanuti-Melozitna divide. At the latter locality they give way on the west to dark, aphanitic, less schistose rocks whose significance is not clearly understood.

Limestones are entirely absent, so far as observed, from the head-water regions of Ray, Kanuti, Melozitna, and Tozitna rivers.

YUKON SECTION ABOVE MELOZITNA RIVER.

The uplands bordering on the Yukon for 30 miles above the mouth of Melozitna River are made up chiefly of metamorphic rocks. Farther from the Yukon, on the north, granitic intrusives prevail.

The metamorphic rocks of this section include greenstones, schists, and limestones. The greenstones are in places gneissoid or even schistose, but for the most part they exhibit only slight mechanical alteration and are plainly derived from basic volcanic rocks. The limestone members are in narrow bands that trend northeast, in accordance with the general structure of the region. Quartz-mica schists in minor amounts are associated with the limestones and greenstones. These rocks are in general not so highly altered as those of the Ray-Kanuti area, and this fact, together with the presence of the limestones, may indicate a stratigraphic and age distinction.

GOLD HILL DISTRICT.

The uplands north of Yukon River for about 30 miles below the Tozitna, including the Gold Hill district, are made up of metamorphic rocks. For some distance below the Tozitna schists occur exclusively, the prevalent types of which are light-colored quartz-mica schists and schistose quartzites. Farther downstream dark slaty schists are associated with the light-colored varieties. Below the mouth of Mason Creek and in the divide at the heads of the small local tributaries of the Yukon is an assemblage of greenstones, limestones, and schists that closely resemble those of the Yukon section above the Melozitna, already described.

RAMPARTS SECTION.

The rocks of the Rampart section, extending for 50 miles above the mouth of the Tanana, consist of a metamorphic assemblage intruded by large granitic masses. The metamorphic rocks include limestones, schists, and greenstones, the first two types predominating.

The limestones occupy considerable areas along this section of the Yukon, to the exclusion of all other types. They generally exhibit strong metamorphism. The purer rocks are intricately banded, owing to flowage, and the impure rocks are strongly schistose. Mica is the most abundant secondary mineral, but garnet, epidote, and scapolite also occur. The replacement of calcite by a chertlike form of quartz is a common phenomenon, which in places has brought about a complete change in the chemical composition of the rocks. The limestones are mostly nonmagnesian blue and white banded rocks, containing more or less secondary silica. Buff-colored dolomitic members are exposed in places in the river bluffs, but their extent and relations were not determined.

The schistose rocks of this section include schistose quartzites and limestones and quartz-mica, graphitic, slaty, and greenstone schists. There are also feldspathic schists and gneisses that are probably more closely related to the granitic intrusives than to the older metamorphic rocks.

The uplands for about 10 miles north of Tanana are occupied by the southwesterly continuation of formations that crop out along the Ramparts section of the Yukon. The lower hills and ridges are generally covered by Quaternary alluvium, but outcrops of quartz-mica schist and cherty limestone are to be found here and there. The more elevated areas farther north, about the headwaters of Bear Creek, are occupied chiefly by dark-colored, slightly altered volcanic rocks that are decidedly younger in appearance than the greenstones associated with the limestones and schists.

STRATIGRAPHY.

Although the available data respecting the metamorphic complex, gathered in a hasty reconnaissance and by more or less linear surveys, point to certain general distinctions among its members, they furnish only a meager insight into the stratigraphy of the assemblage. The respective parts that igneous and regional metamorphism have played in developing the present rock types are not clearly defined, so that the degree of alteration of any rock is not a fair criterion of its stratigraphic position with respect to the other members. The general absence of fossils and of structural data as to the relative age of different members leaves the stratigraphy of the complex to be determined, if possible, by more detailed future surveys.

STRUCTURE.

Mention has been made of the secondary structure developed in the members of the metamorphic complex, in part by regional deformation and in part by the more local deformations incident to igneous intrusion. As the local deformations in many places tend to parallel the margins of the granite masses they necessarily show a wide discordance in any considerable area. There remain to be described the general trends of formations and of the secondary structures that indicate the nature of the broader deformations which have affected the region.

In the Yukon section above the Melozitna and in the uplands of the Gold Hill district there are conspicuous limestone bands that trend in a general northeast direction. Distinctive belts of schist and greenstone have the same trend, and the secondary cleavage planes of the schistose members are conformable in strike with these structural features. Details of the structure exhibited in local exposures reveal closely appressed and overturned folds, with secondary cleavage developed parallel with the limbs of the folds throughout the mass. The dips are generally strong, but locally they are negligible. Within the Gold Hill district they range from 90° to low angles both to the southeast and to the northwest.

At the lower end of the Ramparts section the prevailing structural trends are N. 35°–50° E., but farther upstream, near the granite areas, they are rather erratic. In the Ray-Dall divide and in the Ray-Kanuti divide as far west as camp 9 (see Pl. II, in pocket) a general northeasterly structural trend is indicated by the elongation of the smaller intrusive bodies in this direction and by the observed attitude of the cleavage planes of the schists. In this region no evidence as to the general trend of formations was procured. The same type of close folding noted in the Yukon sections is here evident in some of the greenstone members. (See Pl. III, *C*, p. 12.)

Westward from camp 9, along the north margin of the great granite area, the observed strikes range from west to N. 40° W. and apparently the structural trends are all within the northwest quadrant. This agrees with the general direction of the north margin of the granite area, and it would appear that these features are interrelated. As the structural trends both east and west of the granite area and generally over the region away from the granites are in the northeast quadrant, and as the structures near the larger granite areas in many places have been complicated by compression in two or more directions, it appears probable that the earlier structural features of the entire region had northeasterly trends and that the variations from these trends may have been induced by the agencies and at the time of the granitic intrusions. However, in post-Cretaceous time the region has been subjected to tectonic compression in a northeasterly direction, resulting in the northwesterly trend of the Cretaceous rocks to the west, as described later in this report. The stresses that brought about this deformation probably had little effect on the principal granite masses and were expressed in the development of secondary structure only at the margins of the granites and in the adjacent schists. At any rate the structural trends in the northwest quadrant appear to have been a later development resulting from forces that in some places altered the orientation of the older structure and in others superimposed additional structures upon the rocks that failed to shift into conformity with the tectonic stresses.

AGE AND CORRELATION.

No fossils have been found in the rocks of the metamorphic complex in the Yukon-Koyukuk region, and consequently there is no direct evidence at hand as to the age limits represented by the assemblage or as to the interrelations of its various members. General inferences may be drawn from the resemblance of portions of the complex to the rocks of other sections of interior Alaska whose age is more definitely apparent, but such correlations are necessarily vague and tentative.

The complex probably represents a very great aggregate thickness of beds that were accumulated during a long period of geologic time. The complicated stratigraphy and intricate structure of the assemblage makes it unprofitable to attempt more than to point out the broadest distinctions between its parts and to suggest only the most general correlation with the rocks of other areas.

The rocks of the Yukon sections differ from those of the more northerly area in the abundance of the limestone members. The absence of limestones in the northern area and their abundance in the Yukon sections is so striking that it seems safe to infer that the two areas are occupied by distinct stratigraphic units.

The observations made give the impression that the rocks of the Yukon sections, including the limestones, are younger than the schists of the northern area, but this has yet to be definitely proved. If this inference is correct it is in keeping with possible correlations of the complex of this region with the metamorphic rocks of Alatna River, where Smith[1] found a group of schists lying unconformably beneath limestones similar to those of the Skajit formation of Schrader's John River section,[2] which carries fossils "not older than Silurian nor younger than Carboniferous," and also with the metamorphic rocks of the Rampart and Fairbanks quadrangles, where Paleozoic beds, including Silurian and Devonian limestones, overlie the Birch Creek schist. The rocks of the Yukon sections apparently continue southwestward into the Ruby district, where Devonian fossils have been collected from a limestone associated with greenstones and schists.[3] Plant remains suggesting Devonian age were found by Spurr[4] in clastic beds associated with the limestones in the Lower Ramparts of the Yukon.

If the limestones of the Yukon sections are to be correlated with those of the Ruby, Rampart, Alatna, and John River localities, the areas of the metamorphic complex in the southerly part of the region may be chiefly of Silurian or Devonian age. The apparently older schists may be generally equivalent to the Birch Creek schist of the Yukon-Tanana region and to the older metamorphic rocks of the Koyukuk and Kobuk region and of Seward Peninsula. Their possible age limits may then be placed anywhere from pre-Paleozoic to early Paleozoic time.

GREENSTONES.

DISTRIBUTION.

The term "greenstone" is applied generally to a large class of more or less altered basic igneous rocks that are widely distributed in the region. Those associated more intimately with the limestones and schists of the metamorphic complex have been mentioned. In certain other areas indicated on the map (Pl. II, in pocket) greenstones occur almost exclusively, and it is to these areas that the present description applies.

---

[1] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 60, 1913.

[2] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 55–62, 1904.

[3] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, pp. 21–22, 1914.

[4] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 160–161, 1898.

The principal greenstone area of the region lies along the west side of the Yukon from a point a little below Rampart upstream beyond Fort Hamlin to the margin of the Yukon Flats. These rocks extend westward to upper Tozitna River and underlie much of the lower part of the Ray River basin. North of Ray River their boundary swings to the northeast, cutting across the upland of the Ray-Dall divide about 10 miles from the Yukon. This area is probably continuous beneath the alluvium of the Yukon with the large greenstone area in the northern part of the Rampart district.

A wide belt of similar rocks is traversed by upper Kanuti River. Another considerable area flanks the metamorphic complex on the west near the headwaters of the Melozitna. There are also undefined areas occupied chiefly by greenstone in the uplands eastward from the Melozitna Canyon, in the Gold Hill district, and 10 miles north of Tanana.

LITHOLOGY.

The characteristic rocks of the greenstone assemblage are altered basic igneous rocks, including diabasic and basaltic flows, tuffs, and breccias, and intrusive bodies of similar composition. Associated with these rocks in places are thin beds of slate, chert, and limestone, besides other igneous types—rhyolitic lavas and breccias and light-colored aphanitic laminated rocks that apparently include glassy lavas and fine-grained tuffs. The basic effusive rocks dominate the assemblage in most of the greenstone areas, but locally the intrusives are present in greater amount.

The planes of demarcation between the beds of different types are rarely distinct; generally there is an almost imperceptible gradation from one to another. The composition of the massive flows is essentially the same as that of the fragmental volcanic rocks, and as alteration generally obscures the original structure the difference between flows and coarse breccias is slight. The tuffs grade from coarse fragmental varieties to fine-grained aphanitic rocks resembling the basalts. The finer tuffs in places merge into rocks containing detrital or calcareous materials and through these intermediate types into true slates or limestones.

The basic lavas range in texture from coarsely granular diabase and gabbro to cryptocrystalline or glassy basalt and tuff. The diabase is commonly holocrystalline and exhibits a more or less perfect ophitic texture. The finer-grained rocks usually have an intersertal texture and contain more or less glass. Porphyritic tendencies are common to both the coarse and fine grained rocks, but the phenocrysts are rarely very conspicuous.

Plagioclase and augite are generally the essential minerals, with orthoclase and quartz, or olivine, hornblende, and iron oxides as important accessories. The alteration of the rocks has resulted in the development of numerous secondary minerals, the chief of which are calcite, epidote, serpentine, chlorite, pyrite, and perhaps some of the quartz. The secondary minerals are generally so abundant that they impart a greenish tone to the whole rock mass. The shades vary from light green in some of the finer tuffs to nearly black in the ultrabasic intrusive dikes. Weathered surfaces are generally of a deep-red color, as are also the soils that result from the decomposition of the greenstones.

LOCAL FEATURES.

FORT HAMLIN AREA.

The greenstone area along the Yukon at Fort Hamlin and below is the most extensive in the region, covering more than 1,000 square miles north of the river and extending southward into the Rampart district and eastward into the corner of the Fairbanks quadrangle.

Volcanic effusive rocks comprise the greater part of the assemblage occupying this area. Diabasic and basaltic flows and tuffs of remarkably uniform types are generally abundant, and in large sections of the area no other rocks are to be found. This is especially characteristic of the exposures along the Yukon and in the basin of Squaw Creek west of Rampart.

That part of the greenstone series extending into the Rampart district south of the Yukon contains thin beds of slate, chert, and limestone interstratified with the more massive volcanic rocks. In one considerable area in this district more silicic volcanic rocks are extensively developed, almost to the exclusion of the common greenstone types, and rocks of the same sort are associated in minor amounts with the greenstones of neighboring areas.

West of the Yukon, at the head of Squaw Creek and on the Tozitna, the series is exclusively igneous and the dark-colored varieties are generally predominant. Locally reddish andesitic flows are prominent in the series. The bedded volcanic rocks are cut in the Squaw-Tozitna divide by many basic dikes, chiefly gabbro and diorite, and by a few thin dikes of granite and aplite.

The greenstones of the Ray-Dall divide are similar in composition to those of the Yukon River section, but larger amounts of slate and chert are interbedded with them. They are more highly altered and more or less schistose in the vicinity of the granite intrusions, and farther west the greenstone schist phase is very general. In this part of the area clastic derivatives are more abundant, and apparently there may be a gradation from the greenstone series into the series that has been assigned to the metamorphic complex.

KANUTI RIVER AREA.

The area of greenstones at the head of Kanuti River was not visited by the writer, and the following description is taken from the report of Mendenhall,[1] who traversed the region in 1901 in the course of a reconnaissance from Fort Hamlin to Kotzebue Sound:

> About 27 miles by river west of the portage from the head of the Dall the Kanuti River enters a canyon nearly 30 miles long, cut in rocks of a type entirely different from any encountered in extensive bodies elsewhere. Very compact greenstones of doubtful origin and some fine-grained pyroclastics occur at the head of the canyon. These are intruded by dioritic rocks composed of green hornblende and plagioclase and are succeeded downstream by compact and vesicular basalts and detrital rocks in the form of volcanic tuffs and hornstones veined with quartz. The hornstone resembles some phases of the schist series, but its indurated character is regarded as the result of intrusive masses in its immediate vicinity.
>
> The greater and much the most conspicuous portion of the Kanuti series is made up of intrusive rocks. In certain prominent hills * * * there are masses of ultrabasic rock, often much altered to serpentine, but identifiable in particular cases as pyroxenite and hornblendite. * * *
>
> Greenstones and intrusive bodies, the latter belonging to dioritic or gabbroic magmas, continue to form the valley walls downstream from the occurrence just described until the river passes out into the lower flats, * * * where more recent lavas and tuffs occur.
>
> An isolated hill, 800 or 900 feet high, around whose southern base the river flows just before entering the flats, is the last outcrop examined which belongs to the rocks of this type. It proves to be a mass of serpentine with much later intruded diabase.
>
> * * * * * * *
>
> The rocks which have been grouped together here as the Kanuti series are very diverse in mode of occurrence, but with the exception of the hornstones described above they are generally basic igneous rocks or their pyroclastic equivalents. The oldest members are the greenstones and hornstones, which exhibit considerable alteration. Younger than these are the massive gabbroic rocks (and the serpentines derived from them), which are regarded as intrusive in the bedded greenstone members, while the most recent rocks of the series are the basalts, basaltic tuffs, and diabases, the latter intrusive in certain instances in the serpentines.

UPPER MELOZITNA RIVER AREA.

Dark igneous rocks and greenstones occur in a belt about 6 miles wide east of Melozitna River at the latitude of camps 20 and 21. While these rocks include true greenstones, the predominant types are dense, unaltered hornblendic rocks of uncertain form of occurrence. They are intruded along the line of the writer's traverse by one large and many small dikes of granite, which have produced strong local alteration of the basic igneous rocks.

[1] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, pp. 37–38, 1902.

LOWER MELOZITNA RIVER AREA.

The uplands extending eastward from the Melozitna Canyon are composed largely of greenstone. Specimens taken from the ridge crest overlooking the Yukon 6 to 10 miles east of the Melozitna prove to be characteristic altered diabase and kindred pyroclastic rocks. The textures range from coarse to fine and the colors from dark green or gray to light green. These rocks apparently occur over a considerable area at this locality, but their actual extent has not been determined.

GOLD HILL AREA.

A considerable area in the Gold Hill district, at the head of Grant Creek and farther west, is occupied by dark-colored, more or less altered igneous rocks. The only exposures seen are isolated outcrops on widely separated hills, and little could be determined as to the continuity of the formations between the outcrops, the form of their occurrence, or their relation to the metamorphic rocks that crop out along the Yukon. However, some of the rocks exposed consist of altered diabase, similar to types that occur in the Fort Hamlin area, and locally these rocks probably constitute most of the series. Black hornblendic rocks and diorite occur in some of the exposures. They are but slightly altered and are believed to be younger intrusives cutting the bedded diabasic greenstones.

TANANA AREA.

Basic igneous rocks, some of which are to be classed as greenstones, form the crest of the uplands 10 miles north of Tanana. The area of their occurrence has not been outlined, but apparently they occupy a belt of considerable width trending in a northeasterly direction. They are massively bedded and resistant to weathering, forming prominent topographic features along the divide between Bear Creek and the upper Tozitna. The apparent trend of the formations would carry them southwestward into the not distant Gold Hill district, and it may be that they represent a continuation of the formations that occur at the head of Grant Creek.

STRUCTURE.

The structure of the greenstones and allied formations in the several areas of their occurrence has been discussed under the preceding headings. In summary the data indicate that these rocks generally represent massive lavas and pyroclastic material, originally deposited in approximately horizontal strata. Intrusive bodies, varying in size, are widely distributed in the rocks of this class, and locally they exceed the bedded volcanic rocks in amount. The assemblage has everywhere been strongly deformed, resulting generally in a marked tilting of the beds and, at least locally, in closely appressed, overturned folds and a secondary schistose structure. The development of secondary structure is far less general and intense in the greenstones than in the rocks of the metamorphic complex. Although this may be explained in part as the result of lithologic differences, it seems highly probable that the greenstones have not been subject to all the diastrophic activities that have affected the complex.

AGE AND CORRELATION.

Greenstones similar to those of the Yukon Koyukuk region are widely distributed in interior Alaska, but as a close age determination has been possible in only a few places the definite correlation of widely separate areas is obviously unsafe. The greenstones of the Yukon River section were first described by Spurr[1] as the Rampart series, which he provisionally referred to the Silurian. Later investigations have shown that there may be considerable diversity in age among the greenstones and that most of them are Devonian or younger. The greenstones of the White Mountain area, in the Yukon-Tanana region, are regarded as members of the Tatalina group (Ordovician?) by Prindle,[2] who distinguishes them from other greenstones of the Fairbanks quadrangle that are thought to be of Devonian age. Brooks and Kindle[3] report that greenstones of the upper Yukon are associated with limestones of Middle Devonian age. Mendenhall concludes that the greenstones of the Kanuti group are younger than the schistose series of the Kanuti-Dall divide, which are probably early Paleozoic, and refers them to middle Paleozoic time.

The greenstones of the Yukon-Koyukuk region are probably younger than the metamorphic complex, which includes members of Devonian age. This relation is indicated by the lesser degree of physical alteration of greenstones wherever they occur in considerable areas. The metamorphic complex includes greenstone and greenstone schist members, which are to be regarded as of earlier origin than the more distinct greenstone series.

The significance and relations of the greenstones are probably best indicated by regarding them as the product of volcanic outbursts in more or less widely separated localities during a considerable period of geologic time. At certain times and places conditions were

[1] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 155–169, 1898.

[2] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, pp. 51–52, 1913.

[3] Brooks, A. H., and Kindle, E. M., The Paleozoic and associated rocks of the upper Yukon basin: Geol. Soc. America Bull., vol. 19, pp. 281–284, 1908.

favorable for the accumulation of marine sediment between successive outbursts; at other times conditions favored the recording of only the igneous activities. In places a rather definite transition from one set of conditions to the other is apparent in the relations of a predominantly sedimentary series below and a predominantly igneous series above. The timing of intermittent volcanism and the rate of accumulation of igneous strata are capable of variations so wide that it is obviously unsafe to designate the age limits of these activities. They may have begun as early as the Ordovician in some localities and probably continued in the same general regions through the Silurian and Devonian and possibly later Paleozoic periods. They probably reached a climax in Devonian time, when the rocks of the present major greenstone areas were laid down.

OLDER GRANITES.

DISTRIBUTION.

The older granites of the Yukon-Koyukuk region are associated areally with the metamorphic complex and the greenstones east of Melozitna River. They are designated older granites owing to the wide occurrence in them of gneissic and schistose phases, which in many places exhibit a degree of physical alteration comparable to that of the Paleozoic or older metamorphic rocks, and in order to distinguish them from the unsheared granitic intrusives west of the Melozitna, which are clearly of late Mesozoic age or younger.

The areas occupied by the older granites are generally indicated on the map (Pl. II, in pocket), and in places the gneissic and schistose phases are distinguished from the unsheared types. The altered phases tend to form the peripheries of the larger batholiths, and the unsheared rocks comprise their central areas and many smaller intrusive bodies. Undoubtedly there are many smaller isolated areas of sheared granite included among rocks of the metamorphic complex, but owing to the difficulty of distinguishing them from the other metamorphic rocks they are not shown on the map.

The principal development of the older granites is in a broad belt lying midway between and parallel with Melozitna and Tozitna rivers and continuing northeastward to the Ray-Kanuti divide. The two largest areas form the Kokrine and Ray mountains, respectively. Granitic rocks are reported to border the great Melozitna-Tozitna lowland on the south, and probably the Ray Mountains area extends southward to the northern border of the flats. It may be that the lowland itself is underlain by granite and that the apparently separate major areas are only the exposed parts of a great batholith that extends from the region of Melozitna Canyon to the headwaters of

Ray River. The topography of the unmapped region west of the Yukon in the vicinity of the rapids indicates the presence of granitic rocks over considerable areas.

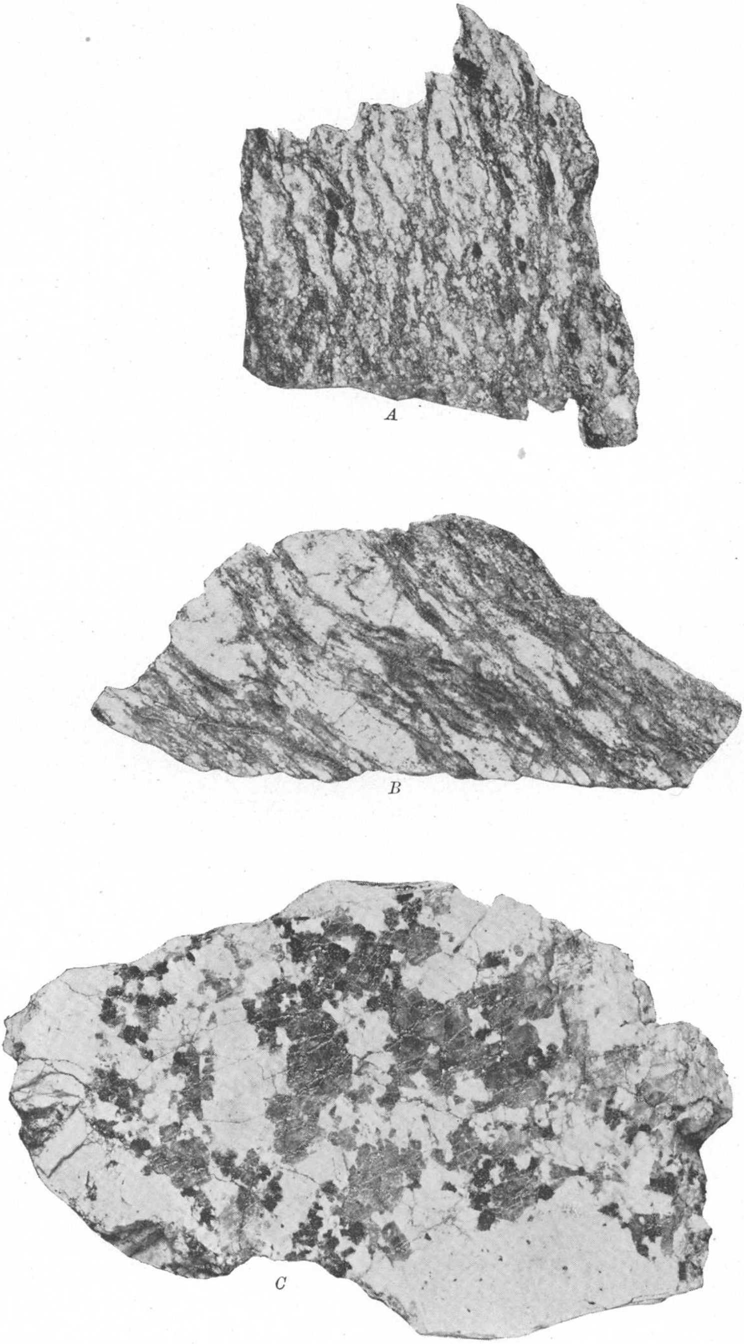
LITHOLOGY.

The older granites exhibit a considerable variety of structural, textural, and mineralogic aspects, as is to be expected of widely distributed and more or less composite intrusive masses that were developed during a long period of igneous activity. The most obvious basis for subdividing the assemblage lithologically is that of secondary structure. The more central parts of the larger granitic masses and many of the smaller intrusive bodies are unsheared granular rocks, while in places the margins of the larger masses and probably many unmapped small intrusive bodies have developed strong gneissoid and schistose structure. This distinction has been shown in the mapping so far as the available data permitted.

The textures exhibited by both sheared and unsheared granites include coarse and fine equigranular fabrics and a great range in porphyritic development. The finer-grained rocks are generally border phases and younger dikes that intrude the more massive bodies. The smaller isolated intrusive bodies are also fine grained as a rule and are without notable porphyritic texture. The more massive bodies of the granite areas are generally coarse grained, and certain phases that occupy extensive areas are remarkable for the great size of the component crystals. Many of the quartz crystals and aggregates are an inch or more in diameter, and throughout large masses the feldspar crystals, which form the larger part of the rock, measure 3 to 6 inches in longest dimension. These phases are not pegmatites but normal granites of unusually coarse crystallization. Porphyritic texture is of common occurrence in both coarse and fine grained unsheared granites and is indicated in the gneissoid and schistose phases by characteristic quartz and feldspar augen. A typical medium-grained porphyritic granite and two augen gneiss phases of probably the same type of rock, collected between camps 15 and 16, are illustrated in Plate V.

The rocks of this assemblage have considerable range in composition. The most widely prevalent varieties are biotite granites, which contain quartz and orthoclase in about equal amounts and plagioclase and biotite in smaller amounts, as shown in Plate V, *C*. Other phases contain more plagioclase and also hornblende or augite and grade from granite into monzonite and diorite. These less silicic phases are, however, of minor areal extent.

The phenocrysts of the porphyritic rock are commonly orthoclase and quartz. The orthoclase crystals generally show Carlsbad twinning and a decided pinkish color. The feldspars of the coarse-



A AND *B*. AUGEN GNEISS ILLUSTRATING MECHANICAL ALTERATION OF GRANITE.
C. GRANITE.

grained granites have the same characteristic, the color being so pronounced that a deep pinkish tone is imparted to whole massive outcrops.

The gneissoid varieties agree closely in both mineral and chemical composition with the granitic rocks from which they were derived. Their alteration was mainly in the nature of physical granulation and rearrangement of the component crystals by flowage. The more schistose varieties, probably including the sericite schists, have been developed from granular rocks in part by physical alteration of some of the component crystals but more largely by recrystallization and molecular rearrangement of the component elements. It is notable that quartz augen are more persistent than those of feldspar, and the presence of fairly definite quartz augen in some of the more highly altered and doubtful schists favors their interpretation as granitic derivatives in which the feldspar materials have entered into the composition of sericite and other secondary minerals.

STRUCTURE.

The older granites are in general intrusive in the members of the metamorphic complex and greenstones. The larger areas include great batholiths, some of which are simple in form while others are a complex product of successive intrusions. Younger dikes occur at frequent intervals cutting the more massive bodies, and in places their variety is great and their relations very complex. They are usually thin and persistent in form for long distances. The smaller granite bodies are generally simple dikes or sills of thick lenticular form. No thin persistent dikes were recognized in the metamorphic areas.

The massive granites are strongly jointed. In the area at the head of Ray River the main joint systems strike N. 60°–80° W. and N. 10°–20° E. A third system has developed almost horizontal planes that in places are closely spaced and give a laminated appearance on weathering. (See Pl. III, *B*, p. 12.)

The secondary structure of the gneissoid and schistose members generally trends parallel with the margins of the granite areas. In the Ray Mountains along the route westward from the headwaters of the Ray this structure trends from west to N. 70° W. In the Kokrine Mountains near the Yukon the trend is northeast. The gneissoid structure is generally developed along the peripheries of the larger granite areas. Rocks probably representing altered granite dikes occur among the members of the metamorphic complex and are similar in kind and direction of structure to the associated metamorphic rocks.

No primary gneiss is known to occur in the region. The gneissoid and schistose structure found in granitic areas are purely of secondary origin, resulting from diastrophic movements that probably varied as to cause, time, and areal expression. Some of the movements were regional and coincident with those that produced the general secondary structure of the metamorphic complex. Later and more local deformative movements, incident to a recurrence of intrusive activities, probably developed many of the peripheral gneissoid phases. The comparatively mild deformative stresses that are recorded in the folding of Mesozoic and younger beds of the region did not notably affect the central areas of the great batholiths, but they may have been concentrated in their effects in the peripheral gneissic zones. The secondary structures of the granites were at least not of synchronous or uniform development.

AGE AND CORRELATION.

The older granites were not intruded simultaneously and perhaps not even during the same geologic period or era. Differences in age are indicated by the composite character of some of the granite masses, which must have resulted from a complex history of recurrent intrusive phenomena at the same locality, involving long periods of time, and by differences in structural aspects as described above. As has been shown rocks of probable Devonian age are included in the metamorphic complex, into which the older granites are intruded. The basic conglomerate of the sedimentary series, believed to be mainly Upper Cretaceous, is in places west of Melozitna River largely made up of granite and gneiss bowlders. Parts of the assemblage are, then, not older than Devonian nor as young as Cretaceous. The physical aspects of many of the granites indicate that they were intruded before the principal alteration of the Paleozoic rocks took place, which may not have been much later than the Devonian.

Post-Cretaceous granitic intrusives occur in the Rampart region and in the region west of Melozitna River. The proximity of these occurrences suggests that rocks of similar age may be included in the assemblage here discussed. In the main, however, it seems best to assign the older granites to the later Paleozoic and possibly earlier Mesozoic periods.

In view of the impossibility of making any definite age determination for the whole or any large part of the assemblage, its strict correlation with the rocks of other localities is not to be attempted. It should be noted, however, that large areas of granite and gneiss probably of similar significance occur in the region to the northeast of the Hodzana uplands and lower Chandalar River.[1] Prindle[2] has

[1] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 471–472, 1900. Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pp. 41–43, 1913.

[2] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, pp. 36–43, 1913.

mapped some large areas of granite in the Circle quadrangle, in the region of Charley River, intrusive in rocks which are probably equivalent to the metamorphic complex of this region and which, locally at least, have developed gneissic phases about their borders. Augen gneiss is also an abundant element of Prindle's Birch Creek schist, corresponding in a general way with the undifferentiated gneisses and sericite schists of the Yukon-Koyukuk metamorphic complex.

MESOZOIC SEDIMENTARY ROCKS.

DISTRIBUTION.

Mesozoic sedimentary rocks constitute the visible bedrock of the entire region between Melozitna and Koyukuk rivers, except in the areas occupied by granitic intrusives and the belts of indeterminate contact rocks surrounding them. The eastern boundary of the Mesozoic rocks follows the main course of the Melozitna for much of its length, but locally they appear for a short distance east of the river. On the north they are probably continuous with the Mesozoic rocks exposed along the Koyukuk below Alatna River. The uplands formed by the Mesozoic sedimentary rocks break off and disappear toward the west at the border of the lowland plains of the Koyukuk and its principal tributaries. Similar rocks crop out at Bishop Rock, a prominent bluff on the north bank of the Yukon 12 miles above the mouth of the Koyukuk, and again west of the Koyukuk for about 50 miles above its mouth and west of the Yukon in the Nulato region. It is highly probable that the alluvium of the intervening lowland plains is generally underlain by the same sedimentary series that forms the bordering uplands, so that the actual extent of the series in the region may greatly exceed that indicated on the map.

STRATIGRAPHY.

These rocks comprise an apparently conformable sedimentary series of great thickness and of great diversity in the lithologic character of the component formations. The base of the series, where recognized, is a massive conglomerate of coarse texture. This is overlain by a great thickness of finer beds, including conglomerates, grits, sandstones, shales, and clays.

The thickness of the series was not definitely determined owing to the generally complex structure and the limitations of a reconnaissance survey. However, the data at hand indicate that it is extraordinarily great. A great number of formations 50 to 300 feet thick were noted at several localities, and peculiarities in lithology and succession seem to distinguish the assemblages of different localities as separate parts of the series. Unless the differences between the rocks of adjacent areas are to be accounted for as due to lateral variation in the aspects of individual beds, the exposed formations of the series must have an aggregate thickness of many thousand feet. This probability is supported by the striking persistence in form and character of individual beds noted in different parts of the region where their strike was followed for miles. The persistence of formations is indicated also by the continuity of characteristic topographic features which are developed on the outcrop of certain beds.

The basal conglomerate ranges in thickness in exposed sections from a few feet to about 60 feet. Its materials in some places are well worn and assorted, but generally there is a great variation in their size and amount of wear which, with their rude stratification, suggests a marine origin. The formation is such as would be produced on a shore line that advanced by destroying pronounced sea cliffs.

The finer beds overlying the conglomerate show better assortment of materials and may represent offshore deposits that were laid down contemporaneously with another part of the basal conglomerate a short distance away. Still higher in the series are cross-bedded sandstones and conglomerates characteristic of stream deposits, interbedded with finely laminated sandstones and shales that are evidently the product of sedimentation in more quiet waters, either in the lateral basins of aggrading streams or as the bottom-set beds of advancing deltas. Probably the whole series was laid down in an area that was subject to intermittent subsidence. At one time a marked subsidence produced marine conditions, and at another a period of stability permitted streams to build deltas and extend their flood-plain deposits over areas that had just previously received marine sediments.

LITHOLOGY.

There is a great diversity in the lithologic character of the various formations of the series. In texture they range from the coarse basal conglomerate through finer conglomerates, grits, sandstones, and shales to impalpable gritless clays. The sandstones and shales constitute much the larger part of the series, the conglomerates and grits are next in abundance, and the clays are developed in thin strata at only a few places.

The basal conglomerate is made up of bowlders of granite, gneiss, and a great variety of metamorphic rocks, such as occur generally in the region east of Melozitna River and probably form the floor on which the series rests. The finer conglomerates of the series consist mainly of quartz, indicating a distinct mode of origin in which weathering, transportation, and assortment figured more largely than in the formation of the basal member.

The fine beds immediately above the basal conglomerate contain a great variety of materials, including quartz and feldspar grains, femic minerals, and fragments of chert, quartzite, and dense igneous rocks. These beds are such as would be formed by a greater comminution of the materials of the basal conglomerate and point to continued sedimentation from the same sources.

The sandstones throughout the series are generally feldspathic, and some of them approach true arkose in composition. They vary in composition, however, and some varieties consist of almost pure quartz sand.

The shales are generally dark-colored gritless rocks, largely of carbonaceous varieties. Some thin beds cropping out in the upland south of Indian River contain so much carbon that they resemble coal in appearance. Other shale members are arenaceous, and one thick bed above the Melozitna Canyon has round quartz pebbles scattered through it, singly and in thin lenses.

STRUCTURE.

The series is massively bedded for the most part, but locally a close horizontal lamination is evident in the sandstone and shale members and a strong cross-bedding in the fine conglomerates. Some of the sandstones also are cross-bedded, and the basal conglomerate has a rude development of the same structure. Alternating beds of thin sandstone and shale form a considerable part of the series in places, as on Indian River at the lower end of the canyon, where such an assemblage, several hundred feet thick, occurs.

The surfaces of many of the sandstone beds show ripple marks and peculiar lobular structures and striations whose origin is not clear. Some of these may represent flowage on steep depositional slopes prior to the deposition of the succeeding beds. Others apparently have been developed by movement along the planes between strata, probably before induration had taken place.

Cleavage structure is common in the massive sandstones and shales. Many of the sandstones break up into conchoidal plates, and weathered surfaces are marked by shallow bowls and basins several feet across. The same structure on a smaller scale develops a fine talus of conchoidal chips. The thinly bedded sandstones, however, generally have a straight cleavage. The shales are generally indurated so that the bedding planes are unrelated to cleavage. Some of them have simple slaty cleavage and others break into long pencil-like fragments owing to a more complex secondary structure.

The series as a whole has been strongly deformed. In general a close irregular folding is indicated, probably accompanied by faulting. The structure of the beds along the west side of the Melozitna

Valley suggests that they owe their present position with respect to the older beds east of the river to pronounced faulting.

There is more or less confusion among the structural trends dominating different sections of the region. On the upper Melozitna near camp 22, where the series was first encountered, the structure seems to be in the form of narrow canoe-shaped folds with the axes trending N. 45° E. A little to the west, on the divide at the head of the Mentanontli River easterly strikes and a northerly dip prevail, and still farther west, on the headwaters of Indian River, the strata dip northeast and strike N. 40°–60° W. The easterly structure is strongly developed along the west side of the Melozitna Valley, southward almost to the Yukon, where it gives way to northeasterly trends. Near the areas of granitic intrusive rock the beds are highly contorted and their original structure is entirely obscured. Pronounced secondary structure is developed in such situations, including flow structure, schistosity, and slaty cleavage.

METAMORPHISM.

TYPES.

Two distinct types of metamorphism are evident in the rocks of the region that are here classed with the sedimentary series. A regional alteration of mild intensity, probably incident to the major deformation of the series, indurated and developed secondary structure in the more susceptible beds without notably affecting their chemical or mineral composition. It had little or no effect upon the resistant sandstones and conglomerates, but it altered shales to slates and kindred rock types. Very locally along the axes of folds a slight schistosity was developed.

The metamorphism of the other type, due to igneous intrusion, is more localized in its expression but of striking intensity. It affected not only the structure of the original rocks, but also their chemical and mineral composition, producing rocks so greatly different in character that their original nature is not directly evident.

IGNEOUS METAMORPHISM.

The granites of the region west of the Melozitna are surrounded by broad irregular zones occupied by a peculiar assemblage of rocks that were probably developed from Mesozoic sediments by igneous agencies attending the intrusion of the granitic magma. The characteristic development of this assemblage adjacent to the granites, where unmistakable sedimentary beds are involved and the metamorphic influence of the intrusions is clearly indicated, leads to the conclusion that the same agencies acting upon similar rocks have produced the peculiar types of the assemblage wherever they appear. The known areas of these rocks, which for convenience are termed "contact rocks," are indicated on the map (Pl. II, in pocket). Although they are generally developed about the intrusive bodies they also occur at considerable distances from the visible contacts. It may be that the areas more distant from known masses of granite have been influenced by intrusive bodies that lie considerably below the present surface or that are obscured by soil and vegetable covering. The granites of the region do not have the topographic prominence usually to be expected of rocks of this type, so that intrusives related to some areas of the contact rocks may not be discovered in the absence of detailed areal surveys.

The contact rocks include a considerable variety of types. The most prevalent are dark-colored laminated rocks in which small lighter-colored phenocrysts are scattered sparingly through a dense groundmass. Some are entirely dense, resembling the groundmass of the porphyritic type in composition; others are but slightly altered arkosic sedimentary rocks in which the characteristic structure is recognizable, although here and there a dense groundmass is developed in the normal or slightly enlarged interstices. Along the contacts with the main granite masses and numerous smaller dikes and in indefinite zones traversing the contact rocks there are rocks containing considerable amounts of granitic material. These rocks contain feldspars and femic minerals, and there are varieties that differ from the typical granites only in the relative abundance of their common constituents. Still another phase of the contact rocks, and one that is of special significance in their interpretation, is a vitreous quartzite formed by reconsolidation of a quartzose conglomerate. In places the quartzite contains granitic materials in small irregular stringers and in the interstices among the original pebbles. The pebble forms are not generally distinguishable near the contact with the granite or in certain zones that exhibit flow structure. In other situations they are more or less distinct and the formation is traceable directly into unaltered phases a mile from the principal contact.

The metamorphism attending the granitic intrusions is plainly indicated by the quartz conglomerate and the finer sandstones and shales associated with it where they abut against the principal granite mass west of the head of Pocahontas Creek. Near the contact the conglomerate is reduced to a solid vitreous quartzite in which the original structure is effaced and secondary structure is induced. This condition prevails for more than 100 feet. Beyond this portion the form of the pebbles can be more or less clearly distinguished. Intrusion of magmatic materials into the conglomerate is indicated for several hundred feet from the contact, and a pronounced induration and silicification extends for over a mile farther. The finer impure sedimentary beds associated with the conglomerate were profoundly altered for even greater distances from the principal contact. Their original structure was effaced, secondary structure was induced by flowage, and the dense, porphyritic igneous aspects characteristic of the whole assemblage were taken on.

It was impossible to collect a complete series of specimens from any single bed of the finer sediments to show the gradation in intensity of alteration away from the granite, as in the conglomerate bed. However, series of specimens from essentially similar beds were procured that throw considerable light on the nature of their alteration and the various stages of the process, from the simple induration of the arkoses at the margins of the metamorphic zones to their most profound alteration at the contact with the intrusive rocks.

In the least-altered phases of the typical arkose of the sedimentary series an induration has taken place by the development in the normal or somewhat widened interstices of a glass or finely crystalline matrix. In the more altered phases the matrix is developed in relatively greater amounts, the quartz and feldspar grains are isolated, and the quartz grains show marked corrosion. A gradation exists in which the quartz grains approach complete resorption and the matrix is developed in progressively greater proportions. In still more advanced phases the more acidic of the feldspars are more or less resorbed, the original basic feldspars are persistent, and secondary basic feldspars and other minerals are developed. The persistent basic feldspars, the secondary feldspars, and masses of epidote and chlorite that replace some of the original minerals of the arkose impart a porphyritic texture to the rock, and the glassy or finely crystalline matrix, developed by the destruction of much the larger part of the original constituents, forms the groundmass.

The alteration of the other sedimentary beds is less clearly traced, but apparently they are represented among the assemblage in the nonporphyritic phases and in the porphyritic phases that carry only secondary minerals as phenocrysts.

Although the genesis of the so-called contact rocks of the region as outlined seems reasonably clear, the areal extent of the assemblage points to a more far-reaching metamorphic effect of intrusive magmas than is generally to be expected. A detailed study would undoubtedly develop the true significance of these rocks and, if they are all of igneous metamorphic origin, the unusual conditions to which the remarkable igneous activities were due. Pending such an investigation it may be well to state certain alternate hypotheses that have been suggested to the writer to account for the occurrence of this assemblage.

If these rocks are not altered sediments equivalent to certain members of the unaltered series in the adjacent areas they must be either a different class of rocks of contemporaneous development or else a series older than the unaltered sediments. It has been suggested, on the strength of the resemblance of certain members of the group to basic lavas, that they represent volcanic effusive rocks developed locally in the general sedimentary area at the time the surrounding beds were laid down, and that the granites represent a recrudescence of igneous activity at the same centers. Also it is suggested that they may represent an older igneous series that has been exposed by the erosion of local anticlines produced by the intrusion of the granites.

There are many rocks in this group which, if taken alone, would be pronounced igneous by any competent petrographer. However, as many of the rocks more or less characteristic of the whole assemblage are known to have been derived from sediments, and as locally the evidence of extensive igneous metamorphism is unmistakable, the conclusion seems justified that the phenomena, determined locally, were of more widespread effect; that the assemblage as a whole was developed by the igneous metamorphism of members of the Mesozoic sedimentary series; and that the occurrence of true basic lavas in the assemblage is doubtful.

AGE AND CORRELATION.

The only fossils collected from the sedimentary series in the Yukon-Koyukuk region have been obtained from the sections exposed in the bluffs of the rivers bordering the region. Numerous collections of fossil plants and invertebrates from the Yukon section below the Melozitna have been determined, and the age indicated has been either Cretaceous or questionably as young as basal Eocene. Reports on collections made in this section in 1907 by W. W. Atwood and the writer are given below:

The invertebrate fossils were determined by T. W. Stanton as follows:

4784. No. 23. Five miles above Louden station:

Ostrea, 2.

Astarte? sp.

As the two species of Ostrea in this lot occur at other places associated with characteristic Cretaceous fossils, it is safe to refer them to the Upper Cretaceous.

4785. No. 24. Bishop Rock:

This lot consists of numerous specimens of Panopæa and one of Cucullæa?. Previous collections from the same place have yielded these species and others that are more characteristic, including Trigonia and Sonneratia, which show that the beds are of Upper Cretaceous age.

The fossil plants were determined by F. H. Knowlton as follows:

No. 18. Ten miles below Melozi station:

Ginkgo multinervis Heer.

Podozamites? sp.

Dicotyledonous fragments.

Cretaceous.

No. 20. Twelve miles below Melozi station:
- Platanus heerii Lesquereux.
- Zizyphus sp.
- Quercus sp.
  - Upper Cretaceous.

No. 22. Five miles above Louden station:
- Dicksonia? sp.
- Podozamites lanceolatus (Lindley and Hutton).
- Zamites sp.
- Ginkgo sp.
- Sequoia sp.
  - Cretaceous.

No. 22a. Five miles above Louden station:
- Podozamites lanceolatus (Lindley and Hutton).
  - Cretaceous.

No. 24. Bishop Rock, 10 miles above mouth of Koyukuk:
- One specimen only, Sequoia subalata Heer.
  - Cretaceous.

The persistence of the essential characteristics of the series and the apparently unbroken stratigraphic sequence of its members between the Yukon and Koyukuk sections suggest that it may represent only late Mesozoic and possibly only Upper Cretaceous sedimentation.

Schrader[1] was the first to recognize Cretaceous rocks in the Koyukuk region. These he divided into the Koyukuk series (Lower Cretaceous) and the Bergman series,[2] which he considered younger than the Koyukuk and more probably Cretaceous than Tertiary. Cretaceous rocks are extensively developed in the region lying to the north and northwest of Koyukuk River, and westward from the lower Koyukuk and the Yukon at Nulato to Norton Bay, where they are known as the Shaktolik group.[3] Evidently the sedimentary series of the Yukon-Koyukuk region represents an areal connection between the Bergman group of the Koyukuk basin and the Shaktolik group of the Norton Bay-Nulato region. It should be noted, however, that these rocks may in part be of Lower Cretaceous age, for Schrader[4] found Lower Cretaceous fossils on the Koyukuk.

The Bergman group has been traced westward from the Koyukuk basin into the Kobuk region, where it is found in extensive areas in the uplands south of the river for nearly its entire length, and in the front ranges of the Endicott Mountains north of the Kobuk from

[1] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 477, 1900.

[2] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 77–78, 1904.

[3] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 79–87, 1913. Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, pp. 54–60, 1911.

[4] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 476–477, 1900.

Beaver River westward to the Mauneluk. Sediments of the Shaktolik type cover large areas on the lower Yukon, and a similar series occupies most of the Iditarod and Innoko districts. South and west of these districts, in the Kuskokwim basin, are immense areas occupied by Cretaceous strata which locally include a considerable amount of volcanic effusive rock. A more purely sedimentary Cretaceous series is found in broad areas on the Alaska Peninsula. Cretaceous beds occur also in the Yukon-Tanana region, on the upper Yukon, in southeastern Alaska, and in places along the north front of the Rocky Mountain system from Canadian territory westward probably to the Arctic Ocean.

In view of the remarkably wide distribution of Cretaceous strata in Alaska and the great thickness exhibited locally by beds of this age, it seems entirely possible that the Shaktolik and Bergman groups, together with their continuation through the Yukon-Koyukuk region, represent essentially contemporaneous sedimentation in a single continuous basin. This broad generalization needs some qualifications, however, as it is by no means certain that the Cretaceous strata do not include sediments of both Upper and Lower Cretaceous age, and that these two epochs may have been separated by diastrophic movements, as shown below.

The age limits of the series are not clearly fixed. The basal conglomerate, presumably the product of an encroaching shore line, while the oldest member of the vertical section at every point, may vary considerably in age from place to place. The oldest bed of the conglomerate that has yielded recognizable fossils occurs east of Tubutulik River at the base of Seward Peninsula and proves to be lowermost Upper Cretaceous. Lower Cretaceous fossils were collected by Schrader[1] from a pinkish limestone which is associated with amygdaloid lavas and andesitic tuffs on the west bank of the Koyukuk a few miles below Hughes. These rocks, which he includes with the Koyukuk group, of Lower Cretaceous age, show a more intense deformation than the Bergman group and presumably the Bergman overlies the Koyukuk unconformably. This interpretation is in accordance with the determined relations of Lower and Upper Cretaceous beds in other parts of Alaska, where generally an epoch of deformation and erosion is indicated between the epochs of sedimentation of the two ages. Presumably, then, the base of the Shaktolik and Bergman groups is younger than Lower Cretaceous.

The upper age limit of the series is less certain. Their great thickness indicates a very long period of deposition, which may have extended from early Upper Cretaceous time into the Eocene. On the

[1] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 477, 1900.

Alaska Peninsula sedimentation continued uninterruptedly from Cretaceous to early Tertiary time, and it may be that the same conditions prevailed in the Yukon-Koyukuk region. Tertiary beds of considerable extent occur in the central part of the Kobuk basin, and Tertiary fossils have been collected from the lower Koyukuk section near the mouth of Kateel River. However, the relations of these beds to the Shaktolik and Bergman groups are yet to be determined. It is not improbable that the latter may contain some of the earliest Tertiary strata. The younger Tertiary beds of the Yukon sections have lithologic and structural characteristics that indicate a history distinct from that of the Shaktolik and Bergman sediments.

YOUNGER GRANITES.

DISTRIBUTION.

The major areas of the younger granites west of the Melozitna are indicated on the map (Pl. II, in pocket). The largest area extends across the northerly headwaters of Indian River and into the basin of Pocahontas Creek. It represents the cross section of an irregular batholith with a general northeasterly elongation. The three other areas mapped farther to the south have the same general form. It is impossible to show on a map of this scale numerous irregularities in their borders, where dikes extend from the main bodies into the altered country rock, and there are numerous thin intrusive bodies apparently separate from them that are not mapped. The complete areal mapping of the region may bring to light additional areas of granite, as these rocks are not conspicuous topographically and the observations of the writer were limited to a narrow zone along the line of traverse.

LITHOLOGY.

The rocks of this class have a great range in texture and composition. The prevalent phases of the larger intrusive bodies are medium-grained, equigranular normal granites. Variations occur on the one hand into pegmatitic and aplitic phases in which the dark minerals are practically absent, and on the other into dark granular rocks that carry hornblende and approach diorite in composition. The more granular phases are developed in the massive intrusive bodies. Fine-grained varieties are more common about the borders of the larger masses and in the younger dikes that cut them and extend into the country rock. The dikes are generally of less silicic composition and include dark-colored hornblendic rocks, indicating an extreme differentiation of the magma during the period of intrusion.

AGE.

The only evidence as to the age of these rocks is their intrusion into the Cretaceous sedimentary series. Presumably they are of late

Cretaceous or early Tertiary age, although they may be considerably younger. In this respect they are similar to the intrusive rocks of the Rampart and Hot Springs districts, the diorites of Christmas Mountain near the head of Norton Bay, and the monzonites of the Iditarod district. It is worthy of note that some auriferous mineralization has taken place in the vicinity of all these intrusives, including those of the Indian River area.

TERTIARY SEDIMENTARY ROCKS.

DISTRIBUTION.

If earliest Tertiary strata occur in the Shaktolik and Bergman sedimentary series, as has been suggested, the conditions of sedimentation, when they are laid down, must have been very different from those prevailing in later Tertiary time, when considerable areas of sediments were deposited in the eastern part of the region. Tertiary rocks occur at a number of places along the Yukon, from the Palisades, 30 miles below the Tozitna, up to the mouth of Hess Creek. They are also reported to occur in the Ray River basin, and there is a small area on Coal Creek, a western tributary of Dall River, near its head.

It is significant that all the Tertiary rocks are deep in the present major erosional depression and that they are generally overlain by Quaternary deposits. In the mapping many of the areas of these rocks have been exaggerated over the actual exposures in order that they might appear on a map of this scale. This exaggeration is justified, however, in that their extension beneath the Quaternary deposits is clearly indicated and the younger material is in places of only a negligible thickness. If the Quaternary cover were ignored in the mapping some of the Tertiary areas, especially those just above Rampart, below the rapids, and at the Palisades below Tanana, should be greatly enlarged. The other areas as shown more nearly approximate the actual extent of the Tertiary beds at each locality.

GENERAL FEATURES.

The Tertiary beds include clays, shales, sandstones, conglomerates, and lignite. They are apparently of fluviatile origin for the most part, the coal beds representing vegetal accumulations in the lateral basins of aggrading streams.

The Dall River area has been described by Maddren,[1] who says:

> These [rocks] occupy a very small area in the upper basin of Dall River on and near the lower part of a west-side tributary named Coal Creek. They comprise soft gray, buff, or black shales standing at an angle of 30° and

[1] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, p. 56, 1913.

associated with a heavy bed of lignitic coal and bone. No fossil plant remains have been found in these beds, but because of their lithologic resemblance to well-determined strata in other parts of the Territory, they are considered to belong to the group of Tertiary lignite deposits.

The area in the Ray River basin is known only from the reports of prospectors. According to these men the outcrops are about in the center of the basin and consist of friable sandstone and shale together with seams of lignite.

The area opposite the mouth of Hess Creek is indicated by outcrops in the river bluff showing thin-bedded, dark-colored shales and sandstones, with which considerable lignitic material is interbedded. The thickest seam of lignite has been mined to some extent. These beds have an almost vertical dip and strike northeast. They have yielded fossils of Eocene age.

On the east side of the river Tertiary beds are exposed in the river bluff between 2 and 3 miles above Rampart. These beds dip steeply to the northwest, so that a thick section is exposed. They include loose conglomerates, light-colored friable sandstones, light-colored clays, thin seams of lignite, and beds of darker-colored shale. Their physical aspect is quite different from that of the beds at the Hess Creek locality, owing to a lesser degree of induration and a generally lighter coloring. They have yielded fossils determined to be Eocene or possibly younger. Beds similar to those above Rampart occur about 2 miles east of Rampart on Hunter Creek, on the left bank of the Yukon a little below Rampart, and on both sides of the Yukon a few miles below the rapids and at the Palisades below Tanana.

On the right side of the Yukon, about 12 miles below Rampart, there is a prominent hill which is probably composed of sedimentary rocks of this type. No recognizable strata are exposed, but the talus over a considerable area is made up of water-worn bowlders and fragments of ferruginous sandstone such as commonly occur in the better-known Tertiary beds of the adjacent region.

STRUCTURE.

The Tertiary beds of the areas enumerated include both thin-bedded and massive members that range in texture from the finest of clays to coarse conglomerates. They generally exhibit considerable deformation, chiefly faulting and monoclinal tilting. Only in a few places is folding evident in broad synclines that trend in a northeasterly direction. The dips are generally high, but locally the beds are almost horizontal for very short distances. No anticlinal structure has been observed in these beds, and evidently they are but the downfolded or downfaulted parts of an original thick and broadly developed sedimentary series.

AGE AND CORRELATION.

According to Arthur Hollick[1] the beds under discussion are of Tertiary and chiefly of Eocene age. In his report he says:

> From the vicinity of Eagle down to Minook Creek, just above Rampart, all the collections of plants are identical in age—that is, they are all Tertiary. The flora is comparable with the Fort Union flora of the States and with the so-called "Arctic Miocene" (now recognized as Eocene) of Iceland, Greenland, British America, and Alaska. It is also comparable with the flora from the type Kenai locality at Kachemak Bay, on Kenai Peninsula.

Hollick also states that the beds which crop out across the Yukon from Hess Creek are Eocene, and that those in the river bluffs above Rampart are Eocene or possibly younger. This suggestion of a possible age distinction between the beds of these two localities is in keeping with their lithologic differences, the beds of the Rampart locality being much less indurated than those near Hess Creek. The Tertiary beds of the various localities downstream from Rampart to the Palisades are inclined to resemble those near Rampart more closely than the beds near Hess Creek, and presumably they also may be regarded as possibly younger than Eocene.

It seems probable that the Tertiary beds of this section of the Yukon basin constitute a fairly thick series and represent a considerable part of early Tertiary time. They are distinctly younger than the youngest beds of the Shaktolik and Bergman groups below the Melozitna, which are "either Cretaceous or questionably as young as basal Eocene." The higher parts of the series include both faunal and floral elements in common with the typical Kenai (upper Eocene) of Kachemak Bay, and, as Hollick suggests, beds still younger may be included in some of the sections.

QUATERNARY DEPOSITS.

GENERAL FEATURES.

A number of different agencies capable of producing detrital deposits have operated in the region with varying persistence during Quaternary time. Glaciers were developed in widely separated localities, and at some places their action was intense. The preexisting drainage systems were profoundly altered, some of them by local glaciers and others, probably, by ice extensions from the Endicott Range to the north and the Alaska Range to the south. As an incident to the disturbance of drainage systems large areas were temporarily inundated by débris-laden waters. Contemporary with the inundation of the low-lying parts of the region and later during the establishment of the present drainage systems, the adjustment of stream

[1] Unpublished report on examination of Mesozoic and Tertiary fossils from about 150 localities in Alaska.

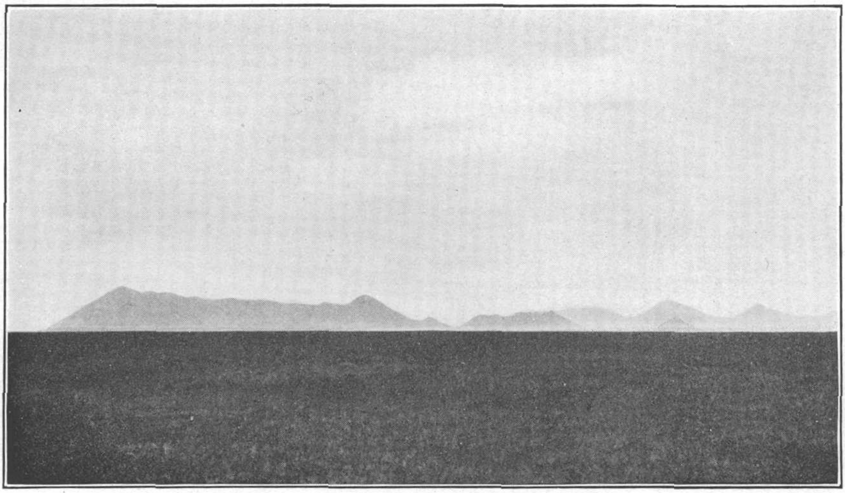
gradients by alluviation or by intrenchment has been constant and broadly expressed. The exposed uplands have at all times been subject to weathering under conditions peculiar to a subarctic climate.

These agencies have contributed to the region a highly complex series of unconsolidated detrital deposits, which include moraines and glacial outwash, lacustrine silts and beach gravels, and a great variety of residual and fluvial accumulations and which combine to mantle almost the entire region. The residual deposits, including the extensive talus aprons of practically all the lower slopes, the waste covering of the lower and many of the higher hills and ridges, and the peculiar terraced accumulations described later in this report, are not shown on the map, owing to their almost universal distribution outside of the alluvial areas and their essential identity with the underlying formations. Among the other deposits a single distinction is made, the recent alluvium of the present streams being differentiated areally from the older terrace and glacial deposits. The definite genetic classification and areal subdivision of the glacial and terrace deposits would be a task far beyond the possibilities of a reconnaissance survey. However, while they are grouped together on the map, the distinctive characteristics of the variously formed types and the general features of their distribution will be discussed in the following pages.

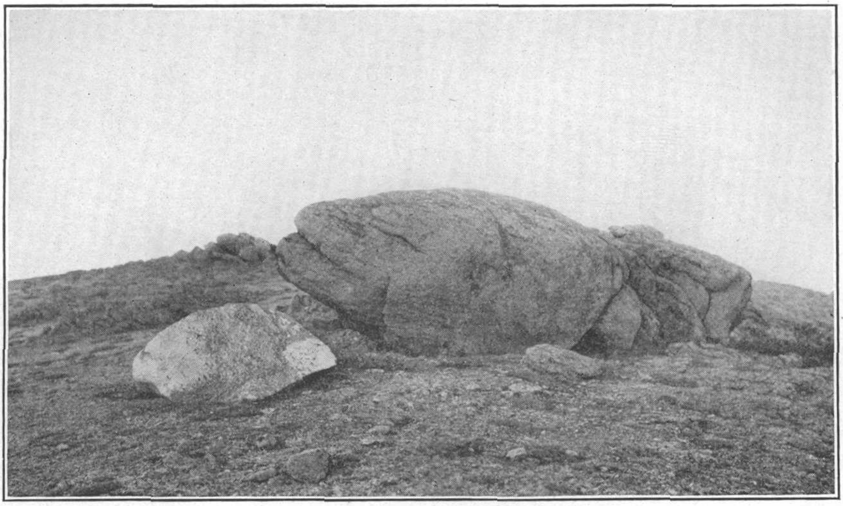
GLACIAL DEPOSITS.

The most extensive glacial deposits are found chiefly in the valleys that head in the Ray Mountains. Smaller glaciers existed in the Kokrine Mountains, which form the Yukon-Melozitna divide, and in the uplands a few miles northwest of the Melozitna Canyon. At each locality the glaciers left characteristic deposits, but except in the Ray Mountains the amount of material laid down was insignificant.

In the valleys of the Ray Mountains there are many well-developed transverse moraines, some of which are more than 20 miles from the main divide. Below the lowermost exposed moraines the valleys are commonly walled by outwash deposits, possibly including buried moraines, in which the postglacial streams have intrenched themselves. Plate VI, *A*, illustrates such an extraglacial deposit that forms a broad, gently sloping ridge between two glaciated west tributaries of Tozitna River near its head. The deposit consists of granite and schist bowlders and blocks, some of which are so large that they suggest actual glacial transportation to their present position, which is considerably beyond the lowest exposed moraine. Plate VI, *B*, shows an erratic bowlder of light-colored fine-grained granite, partly polished, resting on a hill of darker coarse-grained granite about 15 miles from the head of the glaciated valley of the longest southerly tributary of Kanuti River. Adjacent to this hill, which apparently



A. OUTWASH PLAIN NEAR HEAD OF TOZITNA RIVER.



B. ERRATIC BOWLDER, RAY MOUNTAINS.

formed a nunatak in the glacier, is a long morainic ridge standing about 500 feet above the present valley floor and consisting of granite and schist bowlders of various types. Farther down the valley erratic granite bowlders are strewn over a schist bedrock. The rapidity of weathering and destruction of glaciated surfaces is indicated by the forms of the granite in place. Considerable denudation must have occurred here since the ice retreat.

The headward parts of the glaciated valleys have generally been scoured clean of all detrital material and exhibit cirques, hanging valleys, and U-shaped cross-section profiles that are characteristic of intense glacial erosion. Plate IV, *C* (p. 16), is a view looking upstream toward the head of the southwesternmost tributary of Ray River. A hanging valley is seen in the background, and huge granite blocks, loosened from the ice-scoured bedrock by frost heaving, appear in the stream. This part of the valley is practically free from soil or water-worn material.

The general aspect of the recognized glacial features and deposits in the Ray Mountains leads to the belief that tongues of ice extended down the valleys considerably beyond the present outermost exposed moraines, and that morainic materials may form a considerable part of the adjacent lowlands, where the characteristic forms would be obscured by the later outwash and other fluvial deposits.

LACUSTRINE SILTS AND BEACH GRAVELS.

GENERAL FEATURES.

Light-colored even-grained silts are broadly distributed in practically all the drainage basins of the region, and gravel terraces occur in places about their margins. The character of the silts indicates deposition in quiet water; the distribution and form of the gravel terraces point to origin by beach action. As there are other corroborative lines of evidence pointing to the extensive inundation of the low-lying parts of the region, probably during and after the period of maximum glaciation in interior Alaska, the silts are interpreted as deposits made by débris-laden glacial waters, and the high-lying gravel terraces as largely the product of beach action on the shores of lakes that are now extinct. There are also more extensive high-level gravel deposits that are probably of fluvial origin, representing deltas built out into the margins of the ancient lakes by glacial and other streams.

Owing to the ease with which the silts are eroded, they have been removed from many areas which they formerly occupied, and few if any of the present remnants exhibit their highest original depositional surface. During the recession of waters from the region and the progressive intrenchment of the drainage courses, broad, flat surfaces were developed by erosion, and remnants of these surfaces are still to be found in terraces and flat-topped features along the principal rivers and in the basins of their tributaries. The lower terraces are necessarily of later development and are uniformly better preserved than those at higher elevations. The gravel terraces are less subject to erosion and are to be found generally at higher elevations than the silts.

LOCAL FEATURES.

RAY RIVER BASIN.

Typical lacustrine silts and high-level gravel terraces occur in the Ray River basin and on the Ray-Dall divide. The silts form low terraces at the margins of the present flood plain and extend, with gradually increasing elevation, out to the surrounding uplands, where they give way to gravel deposits or to hard-rock formations. Remnants occur at elevations as high as 1,000 or 1,200 feet above sea level, and at lower elevations there are broad areas occupied solely by silts, as, for instance, the broad pass leading northeastward from the mouth of the Ray to the Yukon Flats. The topography of this deposit is generally past maturity; the streams flow through broad, open valleys, and the intervening ridges are rounded and of uneven height. Locally, however, terraced forms are shown, with lakes and swamps lying on the flattened surfaces.

The next pass between the Ray and Dall river basins, 25 miles to the northwest, is floored with a broadly terraced deposit of gravel standing generally at an elevation of about 1,500 feet above sea level. Near the bordering uplands the gravels are coarse and include much material from local bedrock sources. Farther out on the flats they are finer and consist largely of fairly well sorted but poorly rounded quartz fragments. The underlying bedrock is exposed in the side of a scarp near the center of the pass and exhibits a flattened surface overlain by a few feet of gravel. Evidently the same agency that deposited the gravel was capable of beveling uneven bedrock features, and as a possible continuation of a stream channel in any direction is lacking, the agency seems clearly to have been wave erosion. It is likely that the gravels were contributed to the old strand largely by streams from the adjacent uplands, and that they were deposited in part as deltas and in part after being reworked by waves and currents at the margin of the lake.

YUKON SECTION.

Silt deposits are common features along the Yukon except in the narrowest of its gorges. Wherever the valley widens the greater part of its floor is made up of this formation, and the adjoining basins of tributaries are similarly occupied.

The lowermost deposits along the Yukon generally exhibit well-preserved terraces. The deposits at higher levels are of less definite form, grading into irregular remnants of the general deposit that must once have filled the valleys for hundreds of feet above the present stream. The lower terraces are destructional forms carved in the original valley filling by the river itself. Farther back from the river, in the side basins, there are flat-topped features, not so clearly a product of river erosion, which may be remnants of an original depositional surface. The terraces of the Yukon form too complex a system to be fully understood without detailed examination. The general study made by the writer indicates that they are recognizable at a number of levels from 20 feet to 300 or 400 feet above the river. The lower terrace deposits consist mainly of the typical light-colored lacustrine silts. The higher ones, in places at least, are partly rock cut and include gravels in their composition.

A significant development of the silts occurs in an area north of the Yukon below Tanana, where they extend for 4 to 6 miles away from the Yukon into the basins of its tributaries and rise to levels 300 to 340 feet above the river. At these elevations they form broad, flat summits. On the opposite side of the river there are great lowland plains scores of miles in width. The deposits north of the river indicate the minimum elevation to which the adjacent parts of the basin must have been silted up before the present cycle of erosion and the facility with which large areas have been cleared of the deposit. This check on the amount of erosion the silts have suffered favors the conception that even the uppermost silt deposits are but remnants of former widespread deposits that filled the erosional depressions tributary to this section of the Yukon up to elevations of 1,200 to 1,500 feet above sea level.

KANUTI BASIN.

The unconsolidated deposits of the main Kanuti basin have been described by Mendenhall,[1] who says:

> The Kanuti River flows through two basins filled with silt and gravel. In the upper, which is between 10 and 15 miles in length and 4 or 5 miles in width, the deposits grade from coarse river gravels at the upper end of the flats to fine muds and silts at the lower end. They have been deposited by the stream while flowing at its present level, since the silts do not in any observed instances extend above the flood-plain stage of the river. The lower basin of the Kanuti River is more extensive and the deposits more complex. The flats begin about 140 miles above the mouth of the river and extend 100 miles downstream. At first they occupy a valley 4 or 5 miles wide, but near the mouth of a large tributary from the south this valley and the deposits that fill it expand to a width of 20 to 25 miles. Usually the silts stand but a few feet above the water level, but near

[1] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, pp. 43–44, 1902.

the center of this basin there occur several groups of hills composed of silt and sand, which rise from 100 to 200 feet higher. They are remnants of an earlier deeper filling, the rest of which has been removed by erosion.

Extensions from the main alluvial basin of the Kanuti were encountered near camps 13 and 21. Near camp 13 there is a broad alluvial basin of a tributary of the Kanuti which is connected with the main basin, not along the course of the stream, but by a broad, low, lake-studded pass opening through the hills at right angles with the stream. The pass represents an older outlet of the tributary basin, for the stream leaves it through a recent gorge. The character of the alluvial deposits of the basin was not determined, but they probably include both silts and gravels. The maximum elevation of the deposits is several hundred feet above Kanuti River. Near camp 21 there are great areas of low, rolling country underlain by silts and gravels, and at higher elevations there are well-preserved gravel terraces. The topography to the northeast is similar in appearance and suggests that these deposits are continuous with those of the lower Kanuti basin.

MENTANONTLI-INDIAN RIVER BASIN.

The abandoned valley in which the waters of Mentanontli and Indian rivers divide is floored with fine light-colored silts, and terraces of the same material rise over 200 feet above the bottom of the pass. The silts indicate deposition in quiet water. It is significant that the course of Indian River has been profoundly changed. Formerly it flowed northeastward through this valley along the course of the present Mentanontli River, but now it flows southwestward through a canyon, the rim of which corresponds in elevation with the uppermost silt deposits.

MELOZITNA BASIN.

Little is known as to the character of the elevated detrital deposits of the main Melozitna basin. Near the head of the stream both gravel and silt terraces occur, and the valley has a broad alluvial floor. In the main valley there are a number of terraces at intervals up to 100 feet or more above the stream, some of them having broad surfaces dotted with lakes. They are characteristic stream terraces, developed during the removal of a formerly more extensive alluvial filling of the valley.

The upper limit of the old filling of the Melozitna basin is not known, but as the drainage has been completely reversed and the valley probably acted as an outlet for silt-charged glacial waters from the north it probably was aggraded nearly to the elevation of the rim of the canyon near the Yukon. The present topography, however, suggests that such deposits, if they formerly existed, have been removed from all but the lower levels of the valley. (See Pl. IV, *A*, p. 16.)

TOZITNA BASIN.

The Tozitna basin is continuous with that of the Melozitna to the west, and as Tozitna River now flows through a youthful constricted valley for about 15 miles before reaching the Yukon it is probable that the same conditions of sedimentation existed in the two basins. The main course of the Tozitna and those of many of its tributaries lie in a broad alluvial basin of slight relief. Nothing is known of the character of the higher-level alluvial deposits except those on the northeastern headwaters, which are of glacial and extra-glacial origin. Presumably the finer parts of glacial detritus were deposited in the basin during its inundation and may now be found as elevated silt deposits similar to those of other stream basins that head in the Ray Mountains.

KOYUKUK VALLEY.

Alluvial deposits are broadly distributed along Koyukuk River and in the adjacent basins of its tributaries. The silts form a series of low terraces in the valley and may extend to higher levels, but the data regarding their maximum elevation are lacking.

Gravel deposits occur at higher elevations about the margins of the valley and at elevations up to nearly 1,000 feet above sea level in the Hogatza-Pah basin, which is continuous with the Koyukuk Valley. However, the details of distribution and the interrelations and significance of the high-level deposits of the lower Koyukuk and adjacent basins are not well understood. On the whole there does not appear to have been in this valley a pronounced development of high-level silts such as occur along the Yukon, and it is likely that Quaternary sedimentation here had a distinct history from that of the Yukon basin above Ruby.

ALLUVIAL-PLAIN DEPOSITS.

A class of deposits intermediate between the high-level silts and gravels and the modern stream gravels occupies large areas in many of the lowland basins of the region. In part they are analogous to the high-level silts in composition and in part they are made up of younger stream-laid deposits. Because of their composite character and intermediate position they are discussed separately from the true terrace-forming silts and gravels on the one hand and the modern stream gravels on the other.

Alluvial plains occupy the centers of most of the great basins of the region and are especially common features wherever waters divide within a single pre-Quaternary erosional depression. Many of them are scores of square miles in extent, reaching from the lowermost recognizable silt and gravel terraces to the margins of the comparatively narrow modern flood plains.

The relief of the low alluvial plains is rarely appreciable, and generally they are studded with lakes or covered by swamps. Drainage courses are poorly defined, the water seeping from lake to lake for long distances and then finally giving rise to sluggish streams that are but slightly depressed below the surface of the plain.

These plains are generally covered with a dense, low growth of mosses, grasses, and shrubs, so that the character of the deposits is rarely evident. In places, however, along the low scarps at the margins of the present flood plains sections are exposed which indicate that silts of the lacustrine type enter largely into their composition. Stream gravels are inlaid in the silts in places, representing old stream channels, and in other places they overlie the silts. In still other places great accumulations of peat are included in the deposits. Altogether they apparently represent the lower strata of the same series of silts that appear at higher elevations, having been partly reworked or replaced by other materials, chiefly by the action of streams that were controlled by the same base-level for a long period of time.

The depth of these deposits can only be conjectured, but in places it must be very great. For instance, Melozitna River now flows with a grade of several feet to the mile southwestward from its upper basin for nearly 100 miles, to the point where the lowland plains end. Formerly it flowed through the same depression in a northeasterly direction, with at least as steep a grade. If the place where the lowlands end marks a common point on the present and antecedent gradients, it is necessary to conclude that the alluvial filling of the upper basin must be many hundreds of feet in depth. The width of the upper basin—almost 20 miles—accords with this conclusion. The depth of alluvium beneath the lowland plains in other situations is not as clearly indicated, and while generally the depth is probably less than beneath the Melozitna-Tozitna divide and the adjacent portions of these river basins, it is of the same order of magnitude. A prospecting shaft on lower Mason Creek, a Yukon tributary below the Tozitna, is said to have penetrated 135 feet without reaching bedrock. The depth of alluvium is probably rudely proportional to the width of the lowland plains, and very generally in the more extensive plains depths of several hundred feet may be expected.

MODERN STREAM GRAVELS.

The present tendency of erosion throughout the region is toward degradation and intrenchment of the streams below the level of the lowland plains. However, the progress is slow, and most of the streams have developed meandering courses. Incidentally to the migration of meanders down the valleys, the deposits above a certain level, marked by the deepest scouring of the stream, are periodically reworked and redeposited. These materials are classed as modern stream gravels, and owing to the transporting and assorting power of the streams they are generally very different in character from the older deposits that line the modern flood plains. It is not uncommon to find a stream carrying fairly coarse gravels, mostly from headwater sources, traversing the predominantly silt deposits of the lowland plains. A fitting description of such deposits is that they are " inlaid " in the older alluvium.

The modern flood plains are generally but little wider than the meander belts of the streams, which vary according to the size of the stream and the fineness of the stream gravels. The larger the stream and the finer the detritus it carries the broader are the meander belt and the flood plain.

In the mapping it has been the purpose to show only the general character of the distribution of the modern gravels on the several streams rather than their exact margins, and therefore considerable variation in detail is to be expected between the actual and the indicated distribution. In places exaggeration has been necessary in order that the deposit might be shown on a map of this scale, but for the sake of avoiding undue exaggeration the modern gravels on the smaller streams have been omitted entirely.

SUMMARY OF STRUCTURAL GEOLOGY.

The geologic structure of the various terranes that occur in this region has been described in the foregoing pages in connection with their other geologic features. A summary review of the structural geology indicates that at widely separated periods of time the rocks of the region have been subjected to distinct sets of tectonic stresses that differed as to direction, intensity, and structural expression.

The earliest major deformation is recorded in the folding and secondary structure of the metamorphic complex. It affected rocks that were probably of Devonian age and older and apparently preceded the deposition of the greenstone series and the intrusion of most of the older granites. Its stresses were exerted in directions within the northwest quadrant, developing major and secondary structures trending generally in northeasterly directions, in conformity with the dominant tectonic lines of the western part of the Yukon-Tanana region and the region extending southward to the Alaska Range. The structures developed during this period and probably to a lesser extent during the subsequent periods of conformable deformation record the most intense crustal movements that have affected the region.

The greenstones are believed to have been deposited after the major deformation of the metamorphic complex. They have not acquired the pronounced secondary structure characteristic of the metamorphic group, but they have been thrown into more or less closely appressed folds (see Pl. III, *C*, p. 12), the axes of which have the same general trend as the structure of the complex. Whether this difference is a result of superior resistance to the same stresses or whether the greenstones have been subject only to a later and less intense deformation is not clear. The latter possibility, however, seems to fit better the observed structural conditions.

More localized deformational stresses that were more diversified as to direction seem to have accompanied the intrusion of the magmas that gave rise to the older granites. The resulting structures were in general tangential to the borders of the major batholiths. In some places preexisting structures were intensified; in others the older structures were shifted in orientation to conform with the later stresses; and in still others additional structures were superimposed on those of earlier development. As a result the structures about the older granites show a great diversity in complexity and orientation due to several periods of deformation. As the age of the granites is only very generally known, the time of the accompanying deformations can only be conjectured. The composite character of some of the intrusions indicates an intermittent volcanism, so that a long period, probably of late Paleozoic and perhaps later time, may be involved.

A long period of quiescence is indicated by the apparently conformable series of late Mesozoic, probably for the most part Upper Cretaceous sedimentary rocks. Subsequent to their deposition they have been strongly folded, the average dips being about 45°. Here again there is a notable conflict in the directions of structural axes. Along the Yukon and the lower Melozitna the major trends are northeast. Farther north and west easterly strikes are dominant. At the eastern margin of the northern extension of the sedimentary area the strikes are generally northeast. A little to the west they change to east, and still farther west to the northwest. More detailed study of these structures will be necessary to arrive at a satisfactory explanation of this crescentic arrangement of their dominant trends. It may be due to an unequal transmission of general stresses by the underlying terranes, which probably include easily deformed sheared rocks and resistant igneous masses such as those of the older granites to the east. The dominant compression was exerted apparently from the northwest quadrant, the variations from the northeasterly trends being caused by local conditions. The period of this deformation was probably early Tertiary, preceding the deposition of the Eocene and possibly younger Tertiary rocks of the Yukon section.

Local deformation of the same series occurred incidentally to the intrusion of the younger granites, regarding the time of which there are no exact data. The intrusions locally affected the orientation of the sedimentary beds and induced flow structure in some of the more highly altered members.

The last pronounced deformation affecting this region followed the deposition of the Tertiary beds of the Yukon section. It consisted of gentle folding and considerable faulting and was generally of much milder intensity than those of the earlier periods. The Quaternary deposits are undeformed except by local faults of insignificant throw.

GEOLOGIC HISTORY.

INTRODUCTION.

The following summary of the geologic events, believed to comprise the salient features of the history of the region, is based on the data given in the foregoing pages, the interpretation of many of which has been suggested. In bringing together the data concerning the processes that have acted upon the region and their duration and sequence, it is realized that only a very general treatment of the earlier history is justified. The agencies themselves are recorded in the aspects of the various terranes now occupying the surface of the region, but their time relations, except among the later series, are obscure. To avoid needless repetition the age probabilities set forth in the previous pages are assumed as facts, with the reservation that any different interpretation of the stratigraphic data is equally applicable to the following conclusions.

DEVONIAN AND EARLIER TIME.

The earliest geologic activities of which there is any record in the region are those of sedimentation and volcanism resulting in the formation of the rocks now constituting the metamorphic complex. If the conditions under which this assemblage was formed were analogous to those existing in other sections of Alaska and northwestern Canada during the same period—from possibly pre-Cambrian to Devonian time—it is safe to infer that at least several epochs of quiescence and constructional activity were interspersed with epochs of disastrophism and destructional activity. The deposition of fine clastic materials characterized the earlier constructional periods; that of calcareous and igneous materials the later ones. No evidence of the probable interruptions in the progress of sedimentation has been observed in the region, unless the difference in alteration between the predominantly clastic and the predominantly calcareous parts of the assemblage has this significance.

LATER PALEOZOIC TIME.

After the general period of deposition of the metamorphic complex, and probably separated from it by a period of diastrophism in middle Devonian time, there was a notable resumption of volcanic activity, in Devonian and later Paleozoic time, during which extensive accumulations of basic lavas and pyroclastic material were formed in different parts of the region. In places this activity seems to have begun under marine conditions, which later disappeared owing either to uplift or to the accumulation of so thick a series that the depositional surface rose above sea level. Although perhaps not exactly synchronous in their development, the greenstones in the various areas of their occurrence probably represent a single period in which volcanism was the dominant activity.

Igneous intrusive phenomena are recorded in the rocks that have been grouped together as the older granites. The period of their intrusion began before the major deformation of the metamorphic complex and lasted until after the deposition of the greenstones and after the last great deformation of the older rocks of the region, probably into Mesozoic time. During this period massive batholiths, extensive systems of dikes, and composite intrusive bodies were formed. The character of these plutonic rocks indicates that they were intruded beneath a cover of great thickness, which has since been removed by erosion.

Later Paleozoic and earlier Mesozoic time is not known to be represented by any of the bedded rocks of the region. Apparently throughout a long period preceding the Cretaceous the region was a land mass subjected to erosion. This may account for the removal of the great overburden of the older granites before the beginning of the Cretaceous sedimentary period.

LOWER CRETACEOUS TIME.

In the neighboring regions to the north the Lower Cretaceous epoch is represented by volcanic and calcareous terranes, but south of the Koyukuk these rocks are not known to be present. Whether they once extended over the region and were eroded away before the major Cretaceous subsidence or whether the Lower Cretaceous sea never extended so far is not apparent. A period of folding and erosion following the Lower Cretaceous sedimentation has been recognized in other parts of Alaska and may account for this condition here.

UPPER CRETACEOUS AND EARLY EOCENE (?) TIME.

The chief sedimentation of the Cretaceous period began with a general subsidence of the region at the beginning of Upper Cretaceous time or earlier. An inland basin was formed which gradually extended, probably over the whole region. About its margin strong wave erosion developed pronounced sea cliffs on the headlands, and in the estuaries of invaded valleys and offshore from their mouths river-borne materials were deposited. The subsidence was probably intermittent. At one time a marked subsidence produced marine conditions over large areas; at another a period of quiescence allowed the rivers to fill their estuaries and extend their deltas out over areas that had just previously received marine deposits. The base of the series is made up largely of materials of the older granites and associated metamorphic rocks. The higher parts of the series are composed of finer materials derived from similar sources but modified in character by the agencies of weathering and stream transportation.

This period of subsidence and sedimentation probably extended without interruption throughout the Upper Cretaceous and into the early Eocene. It was terminated by a renewal of diastrophism, including folding and uplift. A long period of erosion followed, during which the Cretaceous beds were removed from large areas that later became occupied by younger sediments.

TERTIARY TIME.

To account for the absence of Cretaceous beds beneath the Eocene in the Yukon section and for the gradation from clays and fine sediments in the lower part of the Eocene to sands and conglomerates higher in the series, it is necessary to assume a succession of periods differing greatly in erosional activity, the differences being due probably to orographic changes. Between the Cretaceous and the Eocene sedimentation there must have been a long period of active erosion, in which the Cretaceous beds were removed from the areas noted above. Erosion then weakened, probably keeping pace with a general reduction of grades by the streams. Then followed a long period in which weathering was the dominant process and a mantle of the products of rock decay was formed over much of the country.

Next came orographic changes that quickened erosion over certain areas, the materials probably being redeposited at no great distance from their sources. It is reasonable to suppose that the axes along which uplift started these changes were already determined by prior movements and that they probably coincided with the principal divides of the drainage systems. The uplift, then, first affected the headward portions of the streams most strongly. With their energy thus increased the streams attacked the surface deposits and delivered large volumes of fine débris to the trunk channels, whose capacity was at first probably little affected by the crustal movements. Deposition in the valleys of the larger streams followed. This resulted in a steepening of grades farther and farther from the seat of uplift. The longer the stream the greater would be the thickness of material it must deposit to establish a grade steep enough to carry its load to the sea. As aggradation lifted the streams out of their valleys their flood plains coalesced, permitting the continuous deposition of similar materials over wide areas. During this period the interstream areas were probably at times swamps which were thickly covered with vegetation and in which were accumulated the materials now forming the lignite beds. Shifting of the streams to new courses occurred at intervals as their channels became aggraded above the level of the interstream swamps, giving in each section an alternation of lignite beds and clastic deposits.

Continued uplift, whether steady or intermittent, permitted the streams, after the removal of the decomposed mantle from the area of strongest uplift, to attack bedrock, and during an intermediate period the products of both decomposition and comminution entered into the Eocene formations, the fragmental deposits tending to predominate more and more. In the sequence from the clays and lignites at the base to the sands and conglomerate at the top of the series is recorded the growth of the mountains and the evolution from the placid streams of the early part of the epoch to the mountain torrents that at last probably determined the gradient and character of the streams for the entire distance to the sea.

After the Tertiary beds were deposited the whole region over which they were spread was affected by diastrophism, which resulted in a general uplift of the land and the deformation of the beds. General erosion was renewed in consequence of these movements, and the later Tertiary history of the region is a record of the stages of land degradation. There is strong evidence in many parts of interior Alaska to show that the late Tertiary uplift was not continuous but halted in at least one stage long enough for the reduction of large areas approximately to base-level. This stage was recorded in the Yukon Plateau, a peneplain which was later dissected and whose remnants have been widely recognized. In this stage the Tertiary beds were completely removed from large areas but remained wherever they were flexed or faulted below the level of the peneplain. After the period of base-leveling degradational agencies were again brought into play by further elevation of the land, and the areas of less resistant Tertiary beds became the object of selective erosion. In this stage, principally by the removal of Tertiary beds, the areas of relative depression in post-Eocene time received topographic expression in valleys and lowlands, and this process outlined the orographic features that were to persist to the present day.

QUATERNARY PERIOD.

Erosion subsequent to the elevation of the Yukon Plateau had progressed for a long time prior to the beginning of the Quaternary period and had produced the well-developed system of valleys of a mature topography. The interstream areas were small, many of the lower ones being in the form of sharp ridges.

The most pronounced feature of early Quaternary history was the development of glaciers in the Ray Mountains and other high divides of the region and in the Endicott and Alaska ranges. Ice tongues extending out from the principal gathering grounds formed barriers across many of the drainage courses, behind which the waters were ponded and forced to seek new outlets from their drainage basins.

During this period many of the higher valleys were modified in form by ice scour, the more prominent divides and peaks were greatly reduced in height, and characteristic glacial deposits were developed in parts of the region. In areas covered by the ponded waters a great series of lacustrine silts were laid down. In places about their margins wave action developed sea cliffs and beach gravels; elsewhere stream deposits were laid down in the estuaries of drowned valleys and, perhaps, extended as deltas into the lakes. The finer glacial materials were delivered into the flooded basins and contributed largely to the composition of the silts.

During this time much of the upland area of the region was neither glaciated nor inundated; subaerial erosion and the activities of weathering and solifluction peculiar to a semiarid subarctic climate, described more fully in another section of this report (pp. 75–82), held sway and have since continued.

The principal events recorded in the region during later Quaternary time are the adjustment of streams to their new courses, the extensive removal of the earlier Quaternary sediments, and the progress of the erosional cycle to its present stage. These subjects will be treated more fully in the discussion of geomorphology.

GEOMORPHOLOGY.

PERTINENT DATA.

The present topography of the region is the composite product of various agencies that have operated during its history. In general, earlier constructional and later destructional activities are most strongly expressed in the present land forms. The earlier constructional activities largely determined the distribution and relative susceptibility to erosion of the consolidated rocks, and the later destructional activities brought about the actual development of the present topography under the conditions thus imposed. However, the effects of the opposite processes during these respective periods are far from negligible; the distribution of the older rocks was determined in part by earlier erosion, and sedimentation during early Quaternary time profoundly affected the topography of large areas.

Thus the entire geologic history of the region is related to the subject of geomorphology. The earlier history has already been presented as fully as the data warrant, and the geologic conditions which represent the only product of this period pertinent to this discussion have been described. It remains to treat in greater detail the relatively short period of late geologic history, during which the present topography has been developed.

The point of beginning of this period is necessarily arbitrary, for it is impossible to trace all the characteristics of the present drainage back to their inception. The present discussion will begin with the earliest event that has left a definite impress upon present land forms—the development of the peneplain known as the Yukon Plateau. This event reduced to a minimum the topographic expression of the complex activities which had previously affected the region, and it is the simplest background for the study of the single grand erosional cycle which has followed. The geologic and drainage conditions that existed at the end of the peneplain cycle of erosion held the primary potentials of the present major features of relief and summed up the entire influence of all the earlier phases of the topography upon the present.

PENEPLAIN STAGE.

The development of the Yukon peneplain occupied a long period of erosion under quiescent conditions, subsequent to the deformation of Eocene or possibly younger sedimentary beds. The amount of erosion performed in the peneplanation suggests that the uplift of the region, which ended the peneplain cycle of erosion and initiated the present cycle, may have occurred well past middle Tertiary time.

At the close of the cycle of erosion represented by the peneplain a large province of interior Alaska had been reduced to a surface of very low relief, but little above sea level. Over large areas the land surface was essentially a plain across which streams flowed with gradients adjusted to a minimum load. Elevations arose gradually toward the main divides, which may have had a considerable altitude in places but not a conspicuous relief. The disposition of drainage lines at the close of this period may be indicated by the major erosional depressions of the present topography, but as there may have been irregularities in the subsequent uplift of the region it is not certain that the drainage of the later cycle was inherited intact from the earlier. The rocks involved in the peneplain ranged from the old, indurated, resistant terranes to the younger, poorly cemented Eocene sediments. It is probable that the more resistant older granites had already acquired topographic prominence, forming the main divides at the end of the epoch of peneplanation, as well as at the present time.

LATER TERTIARY UPLIFT AND EROSION.

During later Tertiary time the region was uplifted and a new cycle of erosion began. The crustal movements were probably intermittent and more or less differential, but apparently they had a progressive effect toward higher elevations throughout the region. The streams were rejuvenated, and as elevation of the land went on they intrenched themselves more and more below their former levels. Finally the land rose to its present altitude or higher, and erosion developed a relief considerably greater than the present. The period of uplift was followed by a considerable period of stability, during which the intrenched streams broadened their valleys and lowered their grades, and at the end of Tertiary time the region generally had a topography that was well past maturity, the stage of erosion in each locality depending on the resistance of the rocks in that locality. The Tertiary sedimentary rocks were the least resistant, and by their removal some of the major erosional depressions had been made. The Mesozoic rocks offered only moderate resistance, and the areas occupied by them had been reduced to and below the level of the old peneplain surface. The metamorphic complex and greenstones were more resistant, and their topography was correspondingly more youthful. In places in their areas on the headwaters of the streams remnants of the old peneplain surface probably persisted. The areas of the older granites had probably inherited a superior elevation from the preceding cycle, and in them the rejuvenated streams developed the strong relief of youthful topography.

QUATERNARY PERIOD.

PHYSIOGRAPHY.

At the beginning of the Quaternary period many aspects of the physiography of the region differed from those of to-day. The general relief was stronger, the topography of the several terranes was relatively more youthful, the base-level of erosion was lower, divides and drainage systems differed in many respects from those of the present day, and the glacial aspects and thick series of sediments were still undeveloped.

The most notable feature of the physiography of this period was the disposition of the drainage lines which are believed by the writer to have been as follows: Except for a narrow strip of territory along the present course of the Yukon and the area west of the Melozitna-Koyukuk divide the whole region drained northward. Indian River flowed northeastward along the course of Mentanontli River to join the stream that drained the Kanuti basin; Melozitna and Tozitna rivers joined and flowed northeastward into the Kanuti basin along the present course of the upper Melozitna; and Ray River flowed into the basin of the Yukon Flats through the depression that opens into the flats northeast of its present mouth. It is highly probable that no stream crossed the belt of greenstones along the present course of the Yukon below Ray River at this time, for otherwise there is no tenable explanation of the anomalous conditions of trunk and tributary streams in this section of the Yukon. The present tributaries of the Yukon in this portion of its course—Ray River from the west and Hess Creek from the east—both have broad valleys in the bottom of which alluvial filling of considerable depth has been required to bring the streams into adjustment to the present level of the Yukon at their mouths. Between the mouths of these tributaries the Yukon flows in a canyon, without flood plain or alluvial filling—a fact which plainly indicates that it is still in process of intrenchment and has never flowed at the level to which Ray River and Hess Creek eroded the bedrock depressions in which they lie. If the Yukon had occupied its present course during the erosion of the Ray and Hess valleys, its greater size and capacity at that time should have developed a valley correspondingly broad and deep. Inasmuch as the canyon section at this point does not indicate such an occupancy it seems necessary to conclude that at the beginning of the Quaternary period the upland formed by the belt of greenstones was continuous across the present course of the Yukon, dividing the northward-flowing waters of Ray River from the southward-flowing Hess Creek. If this is true the waters were later diverted from the Yukon Flats basin across this divide—an event of Quaternary history that is discussed on pages 71–72.

The constriction of the Yukon Valley in the vicinity of Ruby repeats in a measure the conditions noted between Ray River and Hess Creek. A deposit of Yukon-borne materials occurs in the basin of Ruby Creek several hundred feet above the present level of the river, an impossible result if the erosion of the two valleys had taken place at the same time with the drainage courses in adjustment. Apparently Ruby Creek developed its valley to essentially its present form before the Yukon assumed its present course through this section. The youthfulness of this part of the valley is more real than apparent, however, for the influence of the Melozitna delta has caused the Yukon to scour its left bank constantly, thus widening the valley far more than it would have done otherwise. Apparently the strip of territory along the present course of the Yukon below Hess Creek belonged to a drainage basin whose trunk stream flowed through the present Nowitna basin[1] into the region now drained by the Kuskokwim. This conception of the physiography of the region at the beginning of Quaternary time is essential to a proper understanding of the later events which have developed the many peculiar features of the present topography.

GLACIATION.

Early in the Quaternary period the conditions of erosion underwent notable changes, apparently owing to the development of local glaciers within the region and to the effect of glaciation in other parts of Alaska upon the drainage of this region. The local glaciation was not pronounced except in the Ray Mountains, where ice tongues extended down valleys from the higher divides for distances of 20 miles or more. These glaciers developed characteristic features, including cirques, hanging valleys, lakes, U-shaped valleys, moraines, and outwash deposits. The chief effects of the glaciers are expressed well within the valleys which they occupied. It is not certain, however, that their action was altogether limited to the confines of the mountain valleys and that they did not at times extend out upon the lowland plains where they come nearest to the main mountain axes.

The indirect effects of glacial phenomena in localities more or less remote from this region, although less readily traced to their origin than those of local glaciation, were nevertheless probably of vastly greater importance in the erosional history of the region. The extensions of glaciers from the Endicott Range are believed by the writer to have dammed the normal outlets of the old Indian, Melozitna, and Tozitna basins and forced them to seek new outlets to the south and west across low points in former divides. The facts in hand are also believed to show that the drainage of the Yukon Flats basin was forced to the southwest through a pass in the uplands between Ray River and Hess Creek. If this is so there is little evidence as to the location of the earlier outlet to this basin, but it might have been to the northeast, through the low silt-filled basins which extend, without interruption so far as known,[2] from the Yukon Flats to the lowlands of Mackenzie River. In that case the diversion to the present course is possibly to be explained by the extension of a

[1] It should be noted that surveys made in 1915 have added to the knowledge of the Nowitna basin. It is occupied for the most part by broadly terraced silt plains at various elevations up to about 1,200 feet above sea level. These continue eastward through the areas drained by Redlands and Cosna rivers to the Kantishna lowlands, which are continuous with those of the Kuskokwim.

[2] Maddren, A. G., personal information.

lobe of the continental glacier from the Keewatin center past Goodenough Mountain, near the mouth of the Mackenzie, where the ice evidently reached an elevation of 3,000 feet.[1] The writer also suggests that the southerly drainage through the present Nowitna basin may have been blocked by ice tongues extending out from the Alaska Range and that the more northerly outlet across the old divide west of Ruby Creek was adopted.

The principles involved in the diversion of streams by glaciers are not new. This action is the commonly accepted explanation of peculiarities of drainage in the glaciated region of the United States that are comparable in both character and magnitude to the peculiarities in the drainage of the Yukon-Koyukuk region and adjacent parts of Alaska. Moreover, this action of glaciers has been suggested as a possible factor in the diversion of Alaska rivers during the development of the present upper Tanana and White river systems.[2] The processes involved are relatively simple, and there can be no question that they have brought about the present arrangement of such systems as those of Indian, Melozitna, and Tozitna rivers. As the changes in the drainage of these basins, which are clearly due to glaciers, are entirely similar to those in the various sections of the present Yukon basin, except in magnitude, there is no reason for not applying the same explanation to the peculiarities of the Yukon Valley unless it can be shown that the glacial factor was inadequate to accomplish the diversion of so large a stream. As stream action was opposed to the northeast by the continental ice sheet, 3,000 feet or more in thickness, and to the south by ice tongues that extended out of the Alaska Range at elevations of 2,600 to 3,000 feet[3] and formed piedmont glaciers that "stretched out across the Kuskokwim lowland,"[4] the glacial factor seems to the writer to be entirely adequate to the needs of the case.

If the pre-Quaternary drainage of interior Alaska had the arrangement outlined above, and the blocking of drainage courses by ice brought about the present form of the Yukon River system, then the striking array of alluviated basins, canyons, terraces, and misfit valleys loses its chaotic aspect in the light of a relatively simple genetic history. The thorough applicability of the hypothesis to every feature and detail of the present topography seems to the writer so convincing as to its correctness that these events are here assumed as facts and the later history of the region as set forth in this paper is based on the conditions that presumably were imposed by these events.

---

[1] Camsell, Charles, Canada Geol. Survey Ann. Rept., new ser., vol. 16, pt. CC, p. 40.

[2] Brooks, A. H., A reconnaissance in the Tanana and White river basins, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 459, 1900.

[3] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 126, 1911.

[4] Idem, p. 135.

INUNDATION.

The inundation of the low-lying parts of the region incident to glacial damming is indicated by the extensive development of lacustrine silts and of rock-cut and gravel terraces and by the youthful valleys that serve as outlets to the alluvial basins. Apparently the waters in the Yukon basin above the ramparts rose to a level that is now 1,500 feet above the sea and in the basin above Ruby to at least 1,200 feet above the sea. The depth of inundation in the Melozitna, Tozitna, and Indian river basins is not so well determined, but probably the level reached corresponded with that of the waters in the basin above Ruby.

The rise of the ponded waters was intermittent, and at numerous stages below the highest it stood at the same level for periods long enough to permit the development of strong terraces. The products of wave erosion at every level were deposited offshore, burying the lower terraces beneath relatively coarse materials. The ponded waters came largely from glacial sources and carried quantities of fine detritus which was deposited in the deeper parts of the basin in the form of silts. The ponded waters extended up the preexisting valleys, forming estuaries. Deltas built by some of the larger rivers not only filled up their entire estuaries but extended far out into the basins. The gravel terraces and deltas were developed at all stages of the inundation up to the highest. The maximum level to which the silts were accumulated has not been definitely determined, but their known occurrence at altitudes as great as 1,000 or 1,200 feet above sea level suggests that the basins might have been silted up completely to the level of maximum inundation. This is not certain, however, and it may be that only the parts of the basins nearest the source of the silts were thus affected.

The time interval represented in the inundation of the region is not clearly delimited. Whether the first effects were due to local glaciers, to those of the Endicott or Alaska Range centers, or to the continental ice sheet in northwestern Canada is uncertain. They plainly resulted from an advanced stage of glaciation, whichever center was first effective, but until the chronology of Alaskan glaciation is more definitely determined the beginning of the period of inundation can be only generally assigned to earlier Quaternary time. The maximum inundation in the Yukon flats basin must have been synchronous with the extension of the continental glacier to the Arctic Ocean; that in the basin above Ruby corresponded with the extension of the Alaska Range glaciers across the Kuskokwim lowland. The inundation of the two basins was not necessarily synchronous. The duration of the period of inundation was determined in each basin by the balance between the forces of aggradation, which tended to replace the waters with sediment, and the forces of degradation, which tended to draw the waters off by lowering the outlet. The elimination of ponded waters from the region probably occurred not long after their maximum elevation had been reached.

LATER QUATERNARY EROSION.

The unglaciated uplands of the region were subject to the processes of subaerial erosion throughout Quaternary time. In the glaciated areas other processes of denudation were temporarily interposed, and in the inundated areas constructional activities were temporarily dominant. With the withdrawal of ponded water and disappearance of glaciers the normal processes of denudation again came into play generally over the region, but under very different conditions from those of the preceding cycle. The gradients of the newly established drainage systems were extremely irregular and showed a general lack of adjustment. The headwater streams had gradients adjusted during the earlier cycle to a lower base-level of erosion; the trunk streams flowed through the basins over soft silts and muds, and at the outlets of the basins they plunged down cataracts through narrow bedrock canyons.

The most pronounced activities that followed the rearrangement of the drainage systems included the deepening of canyons across bedrock barriers and the erosion of the then recently accumulated silt deposits. The rate of intrenchment gradually decreased as adjustment was approached, so that in many valleys it has been prolonged to the present time. The removal of the silts was stimulated by the intrenchment of the bedrock reaches of the streams, which increased the relief of the alluvial areas. The topography of these areas gradually passed through maturity into old age, so that at present the rate of their denudation is not rapid. During the intrenchment of the watercourses broad terracing of the silts occurred in places, and some of these features still persist.

For a long period the trunk channels have had approximately their present gradients. The canyons have gradually widened, some of them to the form of youthful valleys with scant flood plains, but others to only a negligible extent. The tributaries have been variously affected by the grade adjustments of the major streams. Those of the canyon reaches were rejuvenated and are still extremely youthful. Those that flow out into the alluvial basins have had a more complex history. The removal of the silts from their valleys restored the relatively steep gradients that had been developed in adjustment to the lower base-level of the preceding cycle. For a while the streams flowed over these gradients to the margin of the remaining silt deposits and there assumed lower gradients across the easily eroded silts to the trunk channel. As the lower grades over the silts gave less transporting capacity than the steeper grades of the headward bedrock section, deposition of the coarser material took place at the point of transition. Gradually steeper grades were developed over the silt areas through the deposition of materials brought down by the streams themselves, and at the same time the headward grades were reduced by deposition in the lower part of the confined valleys and by continued erosion nearer the divides. The divides themselves were considerably reduced in altitude from that they held at the end of the preceding cycle. The composite effects of these various processes have been to bring the streams into complete adjustment to the present base-level of erosion and to develop some exceedingly interesting deposits and topographic features. The inlaid gravels of the lowland plains were thus formed, and the result of these processes—first by removing silts and later by depositing coarse materials—has been to produce extensive swamps and even lakes of considerable size.

OTHER MORPHOLOGIC PROCESSES.

Other morphologic processes than stream erosion have had an important part in developing many features of the present topography. Climatic conditions throughout the Quaternary period have probably been generally similar to those of the present time and have favored an unusual production and accumulation of rock detritus. The same climatic conditions have engendered an exceptional activity of the processes of solifluction, which have given peculiar and striking forms to the talus accumulations. These processes are grouped for convenience in the following discussion under the terms "weathering" and "solifluction," the first group giving rise to the accumulations and the second imparting to them their characteristic topographic expression.

WEATHERING.

The extreme seasonal variations of temperature and the less pronounced but marked daily variations during critical seasons, characteristic of a subarctic climate, result in unusually rapid production and comminution of talus from exposed bodies of bedrock. On the other hand, the processes of decomposition are held in abeyance by the permanently frozen condition of the ground below a slight depth, which effectually hinders the circulation of ground waters. The mechanical transportation of débris by running water is minimized by a scant rainfall, by frost, and, at lower elevations, by vegetable growth. Consequently talus has accumulated over much of the present land surface, protecting bedrock from the agencies of weathering, except the small exposures on the more prominent features of relief, which are perpetuated through the removal of products of weathering by solifluction.

SOLIFLUCTION.

PROCESSES.

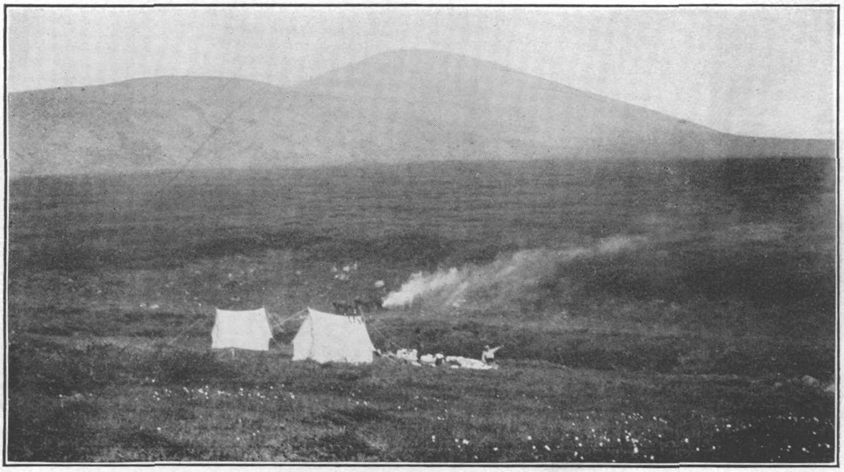
The processes of solifluction, or the migration of detritus under the thrust and heave of frost action, are peculiarly active under subarctic climatic conditions. The character, rate, and topographic product of these processes vary with the nature of the materials affected, with the topographic situation, and with the vegetal covering, so that several distinct types of soil movement and resultant topographic forms are recognizable.

Solifluction is limited to a relatively thin surface stratum. The depth of surface thawing depends on texture, permeability, relief, and vegetal covering. Coarse permeable materials that have strong relief and are barren of vegetation favor depth of thawing; finer, less permeable materials with vegetal covering oppose deep thawing. Consequently the depth of strata in motion under these processes ranges in different situations from a few inches to several feet.

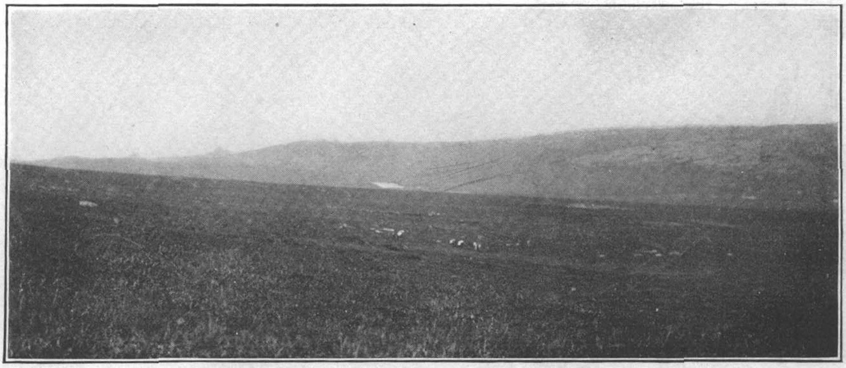
The pressures generated by freezing water are exerted in all directions, but they are expressed in soil movements only upward and horizontally. The vertical expression has been termed heave; the horizontal, thrust. In materials that favor even distribution of water throughout the mass heave is uniform over the entire surface, and no differential vertical movement occurs. Thus, in fine, even-grained materials horizontal movement or movement parallel with the surface is dominant, and even surfaces, either horizontal or sloping, result. On the other hand, irregular capacity for retention of interstitial water leads to differential heave and thrust and to the development of surface irregularities. Moreover, the conditions causing differential heave and thrust tend to accentuate themselves by their own activity, and centers of selective heave are not only persistent but, within certain limits, become more and more pronounced.

The position of the water table with respect to the surface has an important bearing on the character of solifluction processes. Where it is but slightly depressed below the surface during critical seasons, when alternate freezing and thawing occur, it minimizes differential heave and gives a dominant expression to horizontal thrust, the same as is developed in materials that possess a uniform capacity for retaining interstitial water. Where the water table is low differential heave is favored.

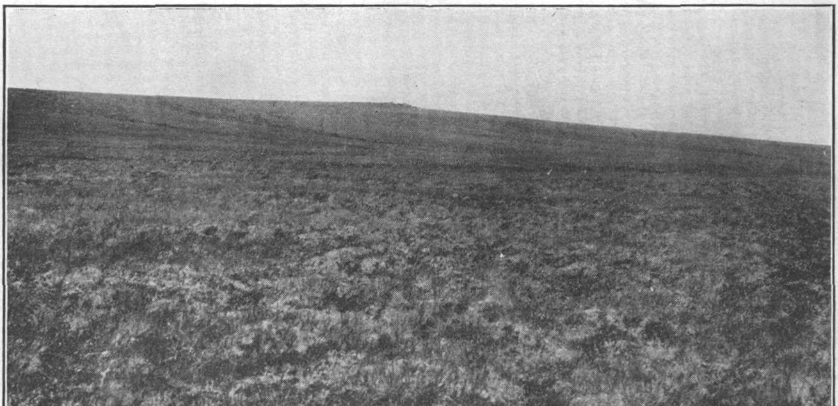
Vegetation tends to limit thawing to a thinner surface stratum and so to elevate the water table closer to the surface. A thin covering favors stronger soil movement; a thick covering retards it. Thus variations in the covering of a slope lead to irregular soil movement and the development of minor surface irregularities.



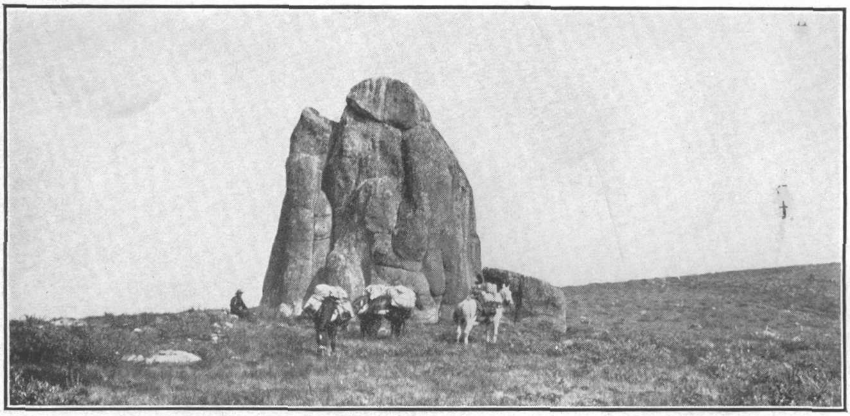
A. SOLIFLUCTION SLOPE AT CAMP 17.



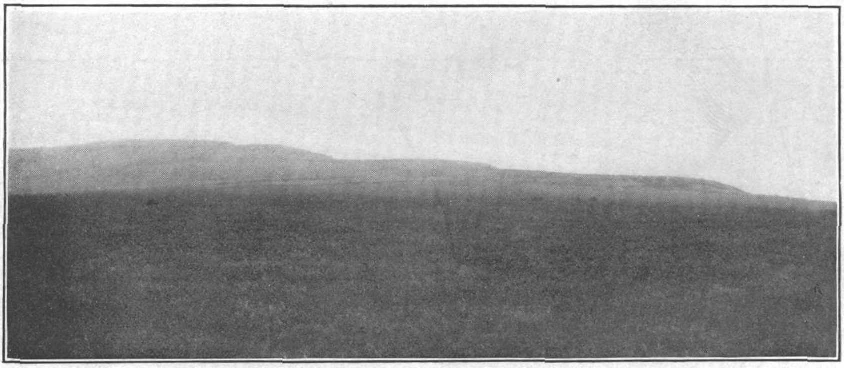
B. SOLIFLUCTION SLOPE IN PROFILE 1 MILE WEST OF CAMP 12.



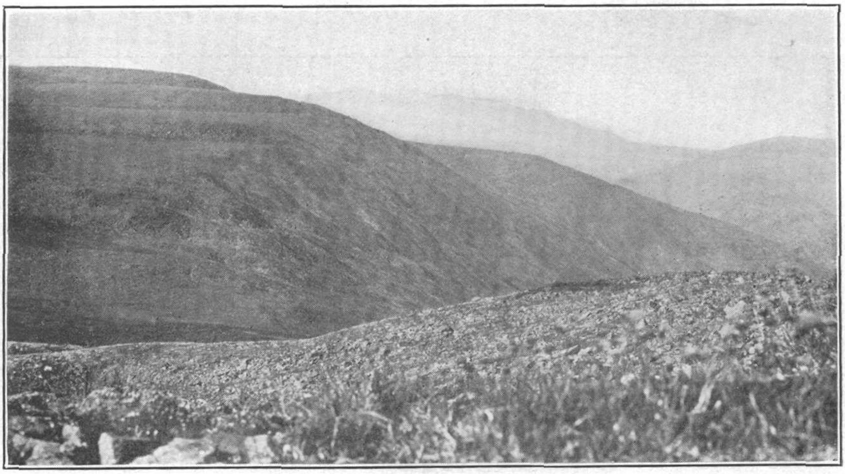
C. SOLIFLUCTION SLOPES OF MATURE DEVELOPMENT. KOYUK RIVER REGION.



A. SOLIFLUCTION SLOPES ENCROACHING UPON A GRANITE BOSS NEAR CAMP 5.



B. ALTIPLANATION TERRACE DEVELOPED IN QUARTZITE SCHIST NEAR CAMP 10.



C. ALTIPLANATION TERRACES NEAR INDIAN RIVER PLACER CAMP.

As the growth of vegetation is affected by altitude and as there is a progressive comminution of materials in the course of their migration from higher to lower levels, there are great differences in solifluction processes and the resultant features at different altitudes. The usual type of talus accumulation at lower elevations is that of broad, continuous aprons that skirt the bases of all the more prominent topographic features; at higher elevations irregular or terraced effects are more frequently produced.

RESULTS.

Major and minor features.—The most widely contrasting major features produced by solifluction are even slopes and terraces. These will be discussed under the terms "solifluction slopes" and "altiplanation terraces," respectively. Many features of intermediate types are produced by the mixed operation of the processes, which are active separately in producing the distinctive types just mentioned. In addition, many minor surface features are superimposed upon the major features, representing details of the processes to which the larger features are due.

In the region under discussion solifluction slopes are typically developed on the talus accumulations derived from the coarser granites, and altiplanation terraces in talus from the metamorphosed and highly indurated Mesozoic rocks. The study of these typical occurrences has furnished many of the data on which this discussion of solifluction is based.

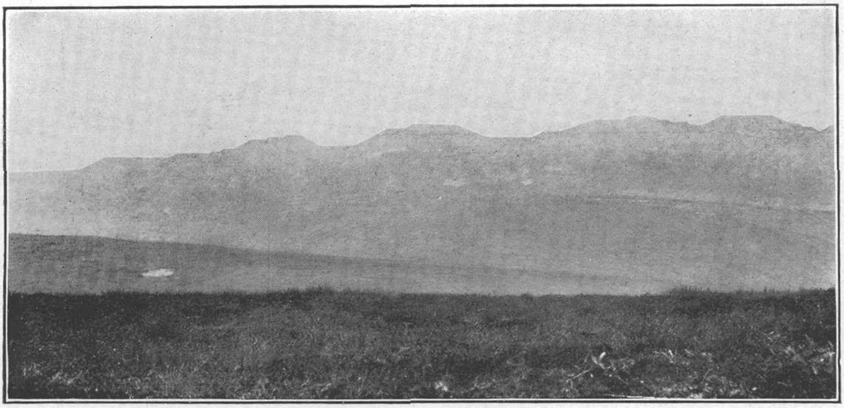
The writer has since had opportunity to test the principles here outlined in other parts of the Territory. Apparently they are effective in developing features of these types over most of interior Alaska and presumably in subarctic regions generally wherever the essential lithologic conditions exist.

Solifluction slopes.—Many bodies of detritus, especially those which form aprons skirting the bases of features of relief, have developed evenly sloping surfaces that extend without break or notable irregularity from their bases to their summits. The base of such a slope is represented by the line along which the material is worn away, such as the course of a stream or the margin of a flood plain; the summit by the line of accession of new material—generally by a bedrock feature near the top of the valley wall or the summit of the feature which the slope flanks. (See Pl. VII, *A*, *B*.) In an advanced stage of development these slopes may merge above with the rounded summits of débris-covered hills or ridges, and their lower margins meet not only along stream courses, but at the bottom of broad V-shaped passes in divides. The angle of slope is determined largely by the transporting ability of the streams eroding their bases. Where a stream is incompetent to remove the materials delivered to it from the solifluction slope aggradation occurs and the slope is reduced. In more mature features a state of equilibrium is evident; the slope is reduced to an angle at which the rate of migration of materials to its base balances the rate of wasting through stream erosion. Where slopes meet in passes and little or no wasting occurs they develop lower and lower angles, finally approaching extinction by building up their bases and lowering their summits. Plate VII, *C*, illustrates an advanced stage in the development of a solifluction slope. Plate VIII, *A*, shows a late stage in the encroachment of solifluction slopes upon a granite ridge. Except at a single point the ridge is entirely mantled by granite detritus, which is obeying the law of migration outlined above.

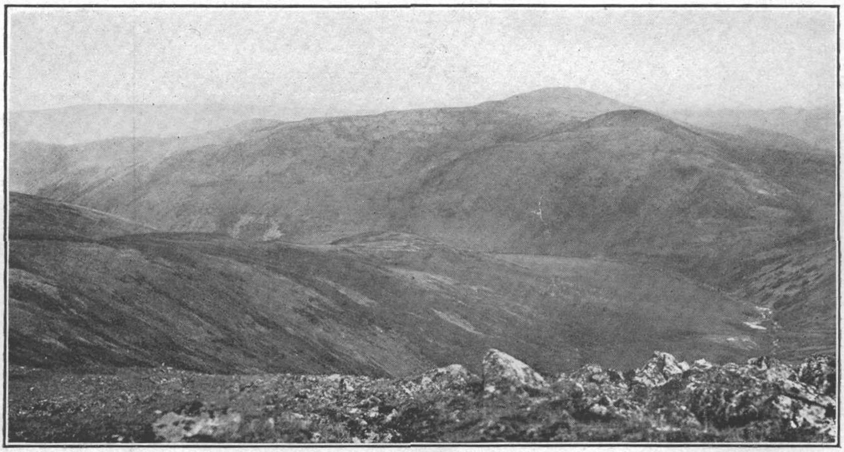
The most typical development of solifluction slopes in the region under discussion is in the talus derived from the coarser granites, which disintegrate readily and produce relatively large amounts of fine materials. Similar features are developed on talus from the unaltered Mesozoic sediments and from many of the schists, which likewise produce fine, uniform detritus or at least sufficient fine material to isolate the larger rock fragments.

Altiplanation terraces.—The author has suggested the term "altiplanation" to designate a special phase of solifluction that, under certain conditions, expresses itself in terrace-like forms and flattened summits and passes that are essentially accumulations of loose rock materials. (See Pl. VIII, *B*, *C*.) Such features are broadly distributed in Alaska. From the international boundary westward into Seward Peninsula and from the Kuskokwim lowland northward to the Arctic Circle there is hardly an extensive landscape in which some of these terraces are not included. In some places but a single terrace may be developed; in others they occur in great numbers, and it is not uncommon to find a mountain group in which every summit and pass is flat and every spur descends in a series of broad, steep-fronted terraces. (See Pl. IX, *A*, *B*.) These features are generally restricted to areas above timber line, but not all such areas support them. On one hill they may be well developed, while on a neighboring hill of equal elevation they are entirely lacking. In the Yukon-Koyukuk region they are most conspicuous in the areas of altered Mesozoic rocks, on certain fine-grained granites, on the more granular greenstones, and on the quartzose schists. As already stated, the granular granites and unaltered sediments favor the development of solifluction slopes. In size these altiplanation terraces vary within wide limits. Their surface area ranges from a few square rods to hundreds of acres. The terrace scarps range in height from a few feet to hundreds of feet.

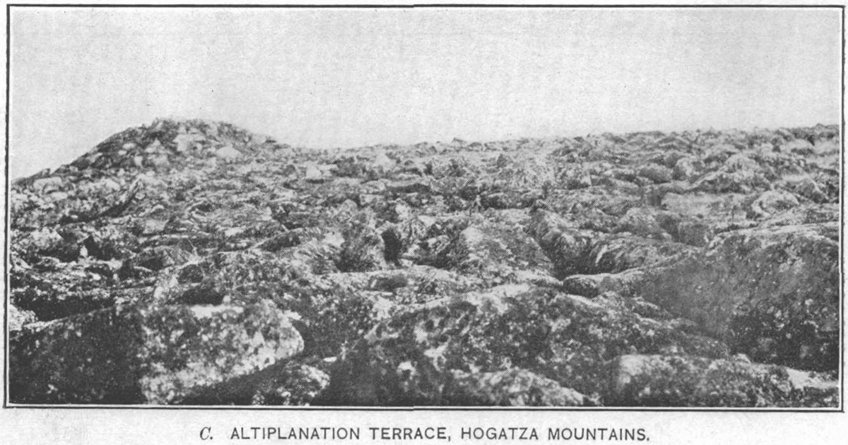
Although these features vary in form, size, and situation, they all have certain characteristics in common. Whatever the situation of a



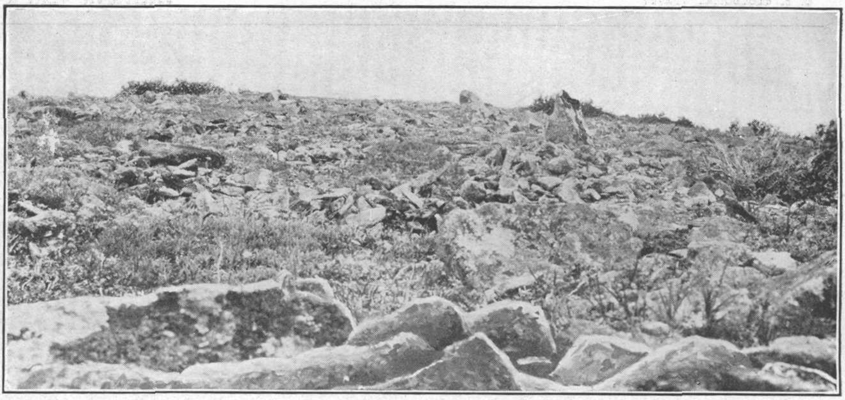
A. ALTIPLANATION TERRACES, MOUNTAINS EAST OF POCAHONTAS CREEK, INDIAN RIVER DISTRICT.



B. ALTIPLANATION TERRACES, EAGLE DISTRICT.

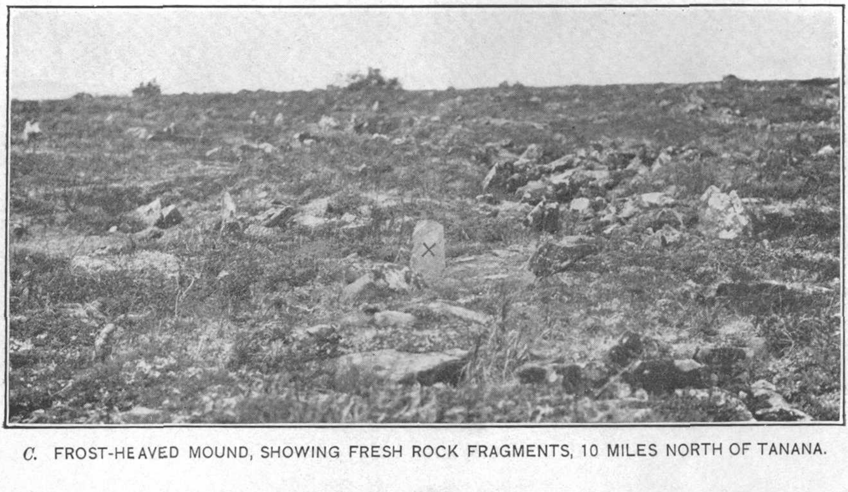


C. ALTIPLANATION TERRACE, HOGATZA MOUNTAINS.



A. ALTIPLANATION FEATURE, 10 MILES NORTH OF TANANA.

B. FROST-HEAVED MOUND, LAKE CLARK-KUSKOKWIM REGION.



C. FROST-HEAVED MOUND, SHOWING FRESH ROCK FRAGMENTS, 10 MILES NORTH OF TANANA.

flat, it is partly or completely bounded by a scarp that drops off to lower levels. The scarp face is commonly devoid of soil and vegetation, is composed of angular talus blocks, and is steep, exhibiting approximately the angle of repose for its component materials. The surface of the flat near the scarp exhibits coarser materials and has less soil and vegetation, less surface water, and less evidence of solifluctional activity than the surface farther back. In a series of terraces there is generally to be found at the base of each scarp either surface water or a growth of moisture-loving plants. Farther out on the flat surface water is absent and the moisture-loving plants give way to more arid forms, and near the downward scarp both soil and vegetation are lacking and the bold talus slope drops off to the level of the succeeding terrace.

Evidence of solifluctional activity is generally present over the flat surfaces, its intensity corresponding with the abundance of soil and the conditions favoring saturation. In general soil is more abundant and more completely and constantly saturated at the inner margin of a terrace, at the center of a flat hilltop, or at the hill margins of a pass. Apparently solifluction is more active in such situations and is gradually less intense toward the outer margins of the flats, until at the rim of the scarp it practically dies out.

The component materials of these features are, without exception, of distinctly local origin. The coarser materials are angular or subangular and not waterworn. The materials are more uniformly coarse at the outer margins of the terraces, where the rock fragments are in contact and interstices are open. Farther back from the scarp fine materials are more abundant and are peculiarly distributed among the coarser materials, giving rise to frost-heaved mounds where they are preponderant, surrounded by depressed zones in which fine materials are absent and coarse materials are in contact. Still farther back toward the inner margins of the terraces plastic residual clays predominate over other materials, and the larger rock fragments are not sufficiently in contact to give rigidity to the mass. However, even where the clays are most abundant it is not uncommon to find large blocks of fresh rock protruding from the surface of the flat.

The size of the materials composing the scarps of these features varies greatly. In places talus blocks weighing many tons are included; elsewhere a scarp may contain only rock fragments measuring not more than a few inches. More generally the materials of the scarps measure from 1 to 3 feet in longest dimension. Plate IX, *C*, shows an altiplanation terrace in the Hogatza Mountains that includes granite blocks 10 to 12 feet in diameter. Plate X, *A*, shows an altiplanation feature 10 miles north of Tanana developed in granular greenstone. The larger blocks in the middle and background protrude 6 and 8 feet, respectively, above the plain.

The only agency now affecting the movement of materials in these features is solifluction, or frost heaving. The flat surfaces are dotted and some of them almost covered with frost-heaved mounds whose materials have so recently come to place that they are entirely free from vegetation. These mounds are composed largely of fine rock materials and clays, but they also contain larger rock fragments, as shown in Plates IX, *C*, and X, *A*. The peculiar distribution of materials giving rise to these frost-heaved mounds is illus-

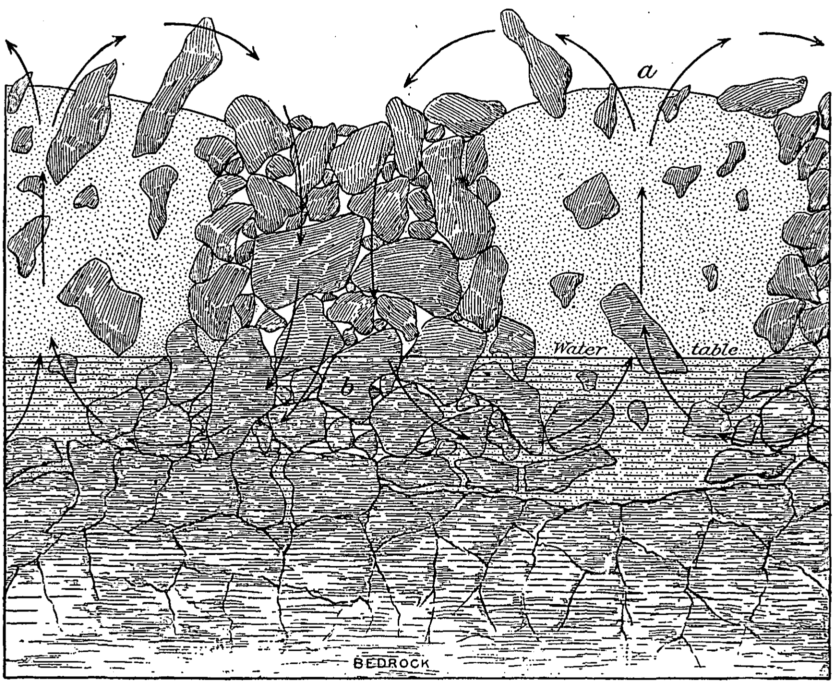


FIGURE 2.—Diagram illustrating segregation of coarse and fine detritus and development of frost-heaved mounds by solifluction.

trated in Plate X, *B*, and in figure 2. The column of clay has greater possibilities of vertical expansion on freezing than the surrounding zone of fragmental material. On the other hand, the expansion of ice develops a greater horizontal thrust in the base of the fragmental zone than in the base of the clay column. Moreover, the circulation of cold air is freer in the fragmental zone, and it seems probable that during each recurrent freeze ice must form in this situation before the clay column is entirely frozen. The greater horizontal thrust at the surface is, of course, in the clay, for in the fragmental zones it is lacking. The character of the mound indicates a strong upward current through its center, and the depression of the surrounding fragmental zones, notwithstanding the evident addition of coarse materials to their surface from the mound, indicates a downward movement. These currents perpetuate the general segregation of fine and coarse materials, until weathering and comminution produce sufficient fines to fill all interstices, when action of this type ceases. This condition is apparent at the inner margins of the better-developed terraces.

The present activity of the mounds is indicated by the freshness of the rock fragments on their surfaces. Plate X, *C*, shows such a fragment (X) protruding 20 inches above the surface of a mound. The short time this rock has been exposed is shown by the absence of the black lichens which cover the other rocks and by the fact that clay still adheres to its surface for several inches above its base. Such fragments are frequently perched upon the side of a mound in a very unstable position and are easily dislodged, sometimes by the tremor produced by footsteps. The rocks topple away from the centers of the mounds and, presumably, a slight general slope of the surface would lead to preponderant movement in one direction. Such a slope toward the outer margin of the terraces exists, and although the addition of talus blocks to the soil-free rim by such a process would be very slow it would undoubtedly keep pace with the reduction of the materials farther back on the terrace to residual clays.

The typical terrace, then, includes an inner zone of fluent materials that assume a level surface under stress of gravity; an outer zone in which a level surface is developed by the action of frost on irregularly distributed coarse and fine materials, and a stable rim, including the scarp and margin of the terrace, composed of angular talus, free from soil and water and consequently from solifluctional activity. As comminution and decomposition progress the inner fluent zone probably encroaches upon the outer frost-mound zone, and the outermost mounds of the latter zone slowly but constantly add talus blocks to the soil-free rim. There is a constant accession of new materials loosened from the underlying bedrock, so that each terrace slowly reduces its altitude and extends its outer margin. In a series of terraces each must encroach upon the inner margin of the next one below. In general the upper terraces are more active than those below, partly because they have a greater daily variation in temperature during critical seasons and partly because they are less protected by vegetation. It is probable that one terrace might overtake and engulf a lower one and that in the course of time the number of terraces has been reduced while their individual areas have greatly increased.

The conditions essential to the process of altiplanation probably include subarctic temperatures, rocks of coarse fragmental character that are slow in comminution and decomposition, low precipitation, absence of strong vegetal growth, and a long period of time. These conditions have been met in many parts of the Yukon-Koyukuk region, and the resultant features locally give a most imposing aspect to the topography.

MINERAL RESOURCES.

PROSPECTS.

Alluvial gold is apparently widely distributed in the Yukon-Koyukuk region, but except those of Indian River the deposits have thus far shown but little economic importance. Gold prospects have been found on a number of northerly tributaries of the Yukon, from Morelock Creek westward to Melozitna River. A little desultory mining has been done on Morelock and Grant creeks, but the production from this whole section of the region has been negligible. Active placer mining on a small scale has been in progress since 1911 on Indian River, in the northern part of the region. A little gold has also been recovered from the south bank of the Koyukuk at a place called Red Mountain, a few miles above Hughes. Gold is said to occur also on some of the southerly tributaries of the Koyukuk below Indian River and on an eastern headwater of Kanuti River.

There are no gold lode mines in the region and but a single prospect. This prospect is on the north side of the Yukon near the bank, about 20 miles below Tanana, and has the distinction of being the first attempt to develop a lode mine in the interior of Alaska. It was opened about 1890[1] but was abandoned soon afterward.

A silver-lead prospect has been opened on Quartz Creek, a small westerly tributary of the Yukon a few miles below Morelock Creek. The mouth of the tunnel is visible from the Yukon, and apparently it is about half a mile from the river and 300 or 400 feet higher in elevation. This prospect was not visited by the writer, but it is described by prospectors as a close stockwork of silver-bearing galena veins cutting limestone for a width of about 10 feet. Specimens from the deposit contain galena, quartz, calcite, and ferruginous materials. The galena in places forms veins several inches across, but usually it occurs as smaller stringers. Much of it shows a curved cleavage, indicating the presence of impurities, possibly due to the silver. The quartz gangue is in part milky vein quartz, stringers of which separate the galena veins in the stockwork. The

[1] Maddren, A. G., The Innoko gold-placer district, Alaska: U. S. Geol. Survey Bull. 410, p. 82, 1910.

contacts between the milky quartz and galena are irregular, and in places the extensions of quartz into the galena mass have a clear glassy aspect. There are also clear, glassy, euhedral quartz crystals embedded in the galena that are not connected with the vein quartz. The ores are said to contain gold and silver in profitable amounts, the silver content having the greater value, but no tests were made by the writer to verify this statement.

INDIAN RIVER GOLD PLACERS.

GENERAL FEATURES.

The principal placers of the Indian River district are on the main stream from 3 to 5 miles below its source. A little gold has also been found on Black Creek, a southerly tributary near the head of Indian River, and on Utopia Creek, which joins Indian River from the west just below the principal placers of the main stream. Prospects are said to have been found also on Pocahontas Creek, which heads against Utopia Creek and flows southward into Indian River near its mouth.

The gold-bearing deposits of Indian River are almost entirely in the immediate bed of the stream. At one place the pay streak is under the east bank of the stream for a short distance, but the gold-bearing stratum is on a level with the stream and does not indicate a true bench deposit. The auriferous gravels are 2 to 6 feet deep and have an average width of about 50 feet. The bedrock throughout the area of profitable placer ground, except on Black Creek, is granite, and the placers are made up chiefly of granite sands and residual bowlders from local bedrock sources. The bowlders have been produced by concentric weathering of the granite rather than by water wear and have been concentrated in the stream bed by the flow of waste from the hillsides under frost action and the removal of the finer materials by the stream. The bowlders make up most of the deposits on Indian River and form a considerable hindrance to economical mining.

Black Creek has not been extensively prospected, but it is reported that placer gold in paying quantities has been discovered at one point in the valley. The depth to bedrock is about 20 feet. The placer is reported to have a width of about 12 feet. The stream is only about 2 miles in length, and the headward part of the valley is very narrow and steep sided. This locality is outside of the granite area and in the margin of the altered Mesozoic rocks, so that the placers are quite different from those of Indian River. The materials include small, well-rounded cobbles and bowlders which offer no hindrance to mining operations.

HISTORY OF DEVELOPMENT.

Gold was first discovered on Indian River by a native. He gave information of his discovery to J. C. Felix, a prospector, who visited the locality in 1910 and found workable placers late in the summer. The first actual mining in the district was done in the summer of 1911, when four claims were worked by 10 men and nearly $10,000 worth of gold was produced.

In 1912 seven claims were worked by about 20 men, with a reported production of $24,500. In 1913 work was done on 13 claims by about 35 men. Operations were greatly curtailed in the early part of the summer owing to low water. Work later in the summer was more successful, and the reported production for the season was about $32,000. Operations were continued on about the same scale in 1914, and gold to the value of about $25,000 was produced. In 1915 operations were handicapped for a part of the season by excessive rainfall and the consequent high water in the creeks. More normal conditions prevailed during the later part of the season, and some production was made from Indian River and from Black and Utopia creeks. The following table shows an estimate of the amounts of gold and silver produced in the Indian River district since mining began in 1911:

Year.	Gold.		Silver.	
	Quantity.	Value.	Quantity.	Value.
	Fine oz.		*Fine oz.*	
1911	154.75	$10,000	60	$32
1912	1,185.19	24,500	142	87
1913	1,548.00	32,000	192	116
1914	1,209.37	25,000	150	83
1915	728.04	15,050	109	55
	5,154.35	106,550	653	373

SUMMARY AND CONCLUSIONS.

The above record of production and mining indicates that the operations conducted up to the present time have been on only a small scale. Indeed, no extensive or very rich placers have yet been found in the Yukon-Koyukuk region. On the other hand, auriferous mineralization has been rather widely distributed. As has been shown, it appears to be connected with the intrusion of later granitic rocks, and therefore the prospector in this field should direct his attention to the contact zones of these granites with the sedimentary rocks. These zones are in part indicated on the accompanying geologic map (Pl. II, in pocket). According to the present information the best hope for the development of a placer-mining industry is in the finding of large bodies of low-grade placers that could be developed by dredges or other cheap methods of exploitation. No such deposits are now known, but it should be added that little search has been made for them. In connection with possible large installations, it should be noted that much of the region is fairly accessible to Yukon and Koyukuk rivers, which are navigable by steamers.

INDEX.

O