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AREAL GEOLOGY OF ALASKA

BY

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ABSTRACT

For nearly 40 years the United States Geological Survey has been collecting information as to the mineral resources of Alaska and making its findings available to the general public through its publications, so that development of those resources that might be profitably exploited could be guided by a body of facts assembled by a competent and impartial agency. On the whole this work has been carried on through field examination of the different mining camps in which valuable mineral deposits have been found, or exploratory or reconnaissance surveys in the parts of the Territory where geologic inferences indicated the possible existence of valuable deposits. Necessarily the results of each individual inquiry have supplied much information which, consciously or not, has given rise to certain generalizations as to broader aspects of the subject than the more or less restricted aspect that was the main purpose of the specific inquiry. In this way a large body of valuable data has been accumulated as to the general geology of the Territory as a whole, though as yet less than half of its nearly 600,000 square miles has been surveyed, even on exploratory standards.

No recent attempt has been made to assemble these data and outline some of the broader features that were disclosed by such a bringing together of diverse information. In 1903 and 1904 Alfred H. Brooks, then in charge of the Geological Survey's Alaska work, compiled the available information on the geology of Alaska and other germane subjects and gave an illuminating summary of the known facts and their interpretation.[1] This valuable reference book filled a much-felt want, and the edition was soon exhausted, so that it is no longer available for distribution from any official source.

During the succeeding third of a century much additional information has been acquired, which has not only added directly to the sum of the knowledge of Alaskan geology but has also allowed reconsideration of many of the earlier views, which necessarily had been based on less comprehensive or less well-substantiated data. For this reason it has seemed desirable to review the available information so as to give a present-day picture of certain of the geologic aspects of the Territory. The aim has been to avoid controversial features or the expression of novel interpretations or correlations that have not yet received general acceptance. This report is thus mainly an inventory of what is currently believed rather than a historical record of the progress by which those views have been reached or a prophecy as to what the future may disclose. It marks only a stage in the problem rather than an end product. In other words, its best service should be not so much to record accomplishment as to point out the things that are not yet known and that therefore challenge attack. As in war, after a successful advance, it is necessary to consolidate the new position and make ready for a new attack, so the accompanying compilation may perhaps serve as a rallying point from which to launch new drives on the now unknown or obscurely seen facts of nature.

[1] Brooks, A. H., Geology and geography of Alaska: U. S. Geol. Survey Prof. Paper 45, 327 pp., 1906.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

Many of the features of a country that exert the most potent influence on the everyday life of its people are largely determined by the geologic formations of which it is composed, the geologic history through which it has passed, and the geologic processes that have operated and are now operating on its geologic framework. Complete understanding of the geology of a country is obviously unattainable, and even slight penetration into the subject covered by that comprehensive term would carry one far beyond the limits imposed by space and time in such a report as this. It has therefore been necessary to pass over many of the interesting and important phases of the subject and select only one of them for discussion. This central theme may be briefly summed up as the description of the general kinds and areal distribution of the major subdivisions of the different geologic formations that make up the visible rocky crust of the earth in Alaska.

Even as thus limited, the subject is too broad for more than the most general treatment here, and in order that the reader may at once be aware of some of the intentional omissions, it is desirable to set down certain things that should not be sought in the report. In a broad sense these omissions fall into two main categories—namely, those imposed by lack of knowledge and those controlled by scale. Of these two defects, lack of knowledge is unquestionably the more serious. By this term the writer does not mean such errors of judgment and interpretation as arise through incomplete knowledge, but actual lack of information. The lack that exists should be apparent when it is realized that less than half the area of the Territory has been surveyed even on the crudest exploratory standards. In other words, areas covering more than 300,000 square miles are entirely unknown except perhaps to the casual trapper, prospector, or native, whose knowledge is not made accessible to others except in evanescent form. It is true that some of these unsurveyed areas lie adjacent to areas which have been mapped and from which it might be possible to infer their geology. It has seemed unwise, however, to give such inferences much permanent weight, and therefore no attempt has been made to record them here. Accordingly, the unsurveyed areas have not been described in the text or colored on the geologic map (pl. 1).

But even among those areas that have been most completely mapped and described there are few that have been studied in sufficient detail to be regarded as well known. As is evident from the subdivisions that have been adopted, only the major geologic eras and systems have been differentiated with enough certainty to be applied over large tracts of country. Thus a vast amount of ignorance is thinly concealed under such widely embracing unit terms as "undifferentiated Paleozoic or older rocks" or "intrusive rocks", which perforce have been adopted in the absence of more adequate differentiation. The areas to which such broad terms have been applied offer a special opportunity for more intensive work, but even in the areas that are now correctly assigned to more specific units the work is by no means finished, for it has been repeatedly proved that in the search for ore deposits much more precise determination of geologic structure and age are essential if the outcome is to be successful. The whole intelligent search for ore deposits is based on the recognition of geologic factors, many of which are obscure or elusive and can be determined only by detailed studies. This report and the accompanying map can therefore only point out some of the more general relations of the broad geologic features, the discussion of the facts set forth being left to the more detailed reports on the specific camps and the economic problems, or to additional field investigations carried on with much greater attention to the details.

The limitations imposed by space have of necessity required the elimination of all but those features that are regarded as most significant. It is inevitable that in such a selection opinions would differ greatly as to what did or did not qualify for retention. The writer is especially aware of the great amount of condensation that has been required and therefore the amount of desirable material that he has been forced to leave out. The reader should therefore be warned against regarding this report as a complete exposition of the geology of the smaller areas, for details regarding which he should have recourse to the many other reports that the Geological Survey has published. These more detailed reports must still continue to be regarded as the authoritative source of information regarding the smaller subdivisions of the Territory.

Possibly the limitations of space, outside the writer's control, are most restrictive in the matter of graphic representation on the geologic map (pl. 1). On such a map, whose scale requires that a distance of 40 miles in nature be compressed into a length of 1 inch on the map, it is impossible to show any but the larger features. In fact, a symbol smaller than one-tenth of an inch in each dimension would be practically illegible, and yet that would be much larger than is required to represent correctly on this map an outcrop covering 15 square miles. The intricate boundaries that in many places mark the junction of two formations in nature must necessarily be conventionalized on the map by broadly sweeping lines that represent only crude approximations to the detailed facts shown in the field. Even though it might be possible in some places to show certain boundaries with precise mechanical fidelity, it has not always been expedient to do so, because an inordinate amount of detail would really obscure the significant facts. For this reason such features as the small bodies of alluvium, which line the courses of practically every stream in the Territory, have been omitted. In that way it has been possible to show the rock formations more continuously and at the same time to emphasize the large significant areas of alluvium, such as the Yukon and Kuskokwim Deltas and the Yukon and Copper River Flats, as they rightly should be among the conspicuous geologic units of the Territory.

In order that endlessly confusing details and exceptions may be subordinated, so that the broader facts may stand out more clearly, the writer has stated most of the text in more positive form than meticulous accuracy would perhaps warrant. It should therefore be taken for granted that such qualifying phrases as "it is believed", "in general", "dominantly", and "so far as known" should be understood as sprinkled most liberally through these pages, so as to remove any appearance that too great finality has been reached. Frankly, there is urgent need for much more specific data regarding all phases of Alaskan geology before most of our present conclusions can be considered well substantiated. It is hoped, however, that the mere expression of the state of present knowledge of the subject may serve to focus attention on the keenest needs, aid in testing more thoroughly current beliefs, and add to the information on which new advances must depend.

ARRANGEMENT

The geologic evidence on which this report rests comes mainly from the interpretation of the facts disclosed by the rocks and materials deposited during the past. These materials naturally are of all kinds, from those laid down in the sea to those formed in swamps on land or through any of the multifarious geologic processes that are operative at present and have been operative as long ago in the past as the records are decipherable. All these materials may be grouped in two major categories, dependent on the principal agencies concerned with their formation—namely, those formed by sedimentation and those formed by igneous action. The sedimentary rocks, as their name implies, are formed of particles worn from preexisting rocks through weathering and erosion and deposited chiefly by or in water, which results in some segregation through sizing and more or less definite layers or strata. Conglomerate, sandstone, and shale are common types of sedimentary rocks. The igneous rocks are those that have consolidated from a molten state, some deep within the earth and some as surface flows or volcanic ejecta. As these two types of rock differ so greatly from each other, the information regarding each can be best treated separately, and the report has been so arranged.

In order that the accompanying descriptions may be presented according to a uniform plan, it has seemed best to follow in general the usual geologic order of starting with the oldest rocks and then taking up progressively the younger formations, those of the present day being mentioned last. In detail, however, it has not proved expedient to adhere to this plan strictly because it would have involved too much skipping about geographically, which would be confusing, and besides the data are not sufficiently exact to permit accurate correlation of the rocks in widely separated areas, even though they may belong in a single geologic system. The major arrangement adopted does not go further geologically than to group together in the same section reference to all the areas in which rocks of a specified period occur. For convenience of reference the descriptions then follow a general geographic order, starting in the southeastern part of the Territory and proceeding in a generally orderly fashion to the extreme northwestern part.

So many of the place names used in Alaska are little known, except locally, that it has seemed worth while to acquaint the reader with some of the principal areal terms used in this report. The principal areal subdivisions used are graphically represented on plate 3. From this diagram it will be evident that the larger subdivisions are called regions and the smaller ones districts, each being given a distinctive name. In the main these subdivisions are made on the basis of certain natural associations, but they are to be regarded only as convenient units rather than strictly geographic entities. The boundaries as laid down have no general acceptance, nor is it intended that they should be rigidly applied even in other Survey publications; moreover, they do not correspond at all closely with any officially recognized legal or administrative subdivisions. Even the names that have been selected are to be regarded merely as catch titles, to be used as convenient, rather than well-founded terms to be perpetuated. Thus, the names, so far as possible, have been limited to single words. Still further subdivision of the districts has been made, as occasion warranted, and for these the term "area", coupled with the name of some local feature, such as a river, valley, mountain, or settlement has been given. Thus, there is the Jualin area in the Juneau district of the southeastern Alaska region.

ACKNOWLEDGMENTS

In assuming the responsibility for the compilation of this report, the writer is keenly aware that his part has been merely that of assembling and coordinating the results of a tremendous volume of material collected mainly by others. It is impracticable to trace in detail the successive steps by which the present knowledge of the geology of Alaska has been built up and thus to credit properly to each of the contributors the specific recognition that his work deserves. Many of the ideas expressed here have grown up Topsy-like, merely through accumulated evidence, until they have become accepted as verities without ever having been definitely formulated or publicly expressed.

If specific reference to the original source were given for each statement made, the text would become a mere adjunct to innumerable footnotes. To avoid such a cumbersome result it has seemed best to call attention here to the principal sources from which the bulk of the material regarding different districts has been taken. This is done graphically on plate 2, by delimiting the areas especially covered by the different reports and letting that serve as an indication that all the facts stated in later pages are drawn principally from the reports specified. The overprinted letters and figures shown on this plate indicate the series and designate the number of the appropriate Survey publication in that series. The Professional Paper series is denoted by the letter P, and the Bulletin series by the letter B, so that, for example, P 109 and B 844 refer to Professional Paper 109 and Bulletin 844, respectively. A list of these and other Geological Survey reports on Alaska is given on pages 4–7.

Necessarily, other reports and articles have been consulted, but where their material has been used specific reference to them has been made at appropriate places.

It will be apparent from plate 2 that practically all the reports referred to are publications of the Geological Survey. In thus drawing so heavily on Survey reports it is not intended to disregard or minimize the innumerable contributions to the knowledge of the geology of Alaska made by other agencies and individuals. Without these contributions much of the work of the Geological Survey would be futile, as it must always be based in large part on the specific observations of the prospectors, miners, and others whose work discloses many of the hidden things in nature. The omission here of more specific acknowledgment to these others is made up for by the fact that full recognition is given to them in the detailed Survey reports that have been mentioned. Furthermore, although these others have contributed largely to the mass of detailed facts, they have been concerned principally with their own individual problems, and only the geologists of the United States Geological Survey have been instrumental in coordinating these details and making them available in the comprehensive form that has been used in preparing the present report.

The list omits many of the earlier publications of the Geological Survey, but the purpose of the writer has been to cite the later and more available publications, especially as most of them give full reference to all the earlier publications on the particular area considered, many of which are still standard. In fact, it is constantly astonishing that most of the pioneer geologists in Alaska reached such correct conclusions in view of the handicaps under which the results were achieved. Some of the conditions of field work in the early days would stagger any but those possessed of indomitable courage and perseverance as well as keen technical insight. Many of the best-founded present-day beliefs were first reached by those early geologists from some chance observation made during the intervals snatched from the racking grind of back-packing or other labors entailed in the grim necessity of self-preservation under the exigencies of exploratory work. The investigations of Hayes, Russell, Dall, Spurr, Mendenhall, Schrader, Rohn, Spencer, Collier, Martin, and a score of others of the early Survey geologists in Alaska are still noteworthy for their enduring value.

Special obligation should be expressed to the present geologic staff of the Alaskan branch and to the late Alfred H. Brooks, under whose guidance most of the development of the branch took place until his untimely death in 1924. In large measure the data in this report are the direct outcome of the field investigations and laboratory studies of S. R. Capps, F. H. Moffit, and J. B. Mertie, Jr., who, with the writer, have had a combined experience in the Geological Survey's Alaskan investigations of more than 100 field seasons. In addition to their original contributions, these men and all the members of the present staff have aided greatly in the preparation of this report by their constant suggestions and critical review of its contents.

LIST OF GEOLOGICAL SURVEY PUBLICATIONS ON ALASKA

[The principal maps in the reports listed below are noted by the following designations: G, geologic map; T, topographic map; GT, geologic map on topographic base]

GENERAL REPORTS

PROFESSIONAL PAPERS:

45. The geography and geology of Alaska, by A. H. Brooks and Cleveland Abbe, Jr. 1906. 327 pp., illus., maps (T, 1:2,500,000, 1:625,000, and 1:250,000).

125–C. Pliocene and Pleistocene fossils from the Arctic coast of Alaska and the auriferous beaches of Nome, Norton Sound, Alaska, by W. H. Dall. 1919. pp. 23–37, illus.

159. The Upper Cretaceous floras of Alaska, by Arthur Hollick, with a description of the plant-bearing beds, by G. C. Martin. 1930. 123 pp., illus.

PROFESSIONAL PAPERS—Continued.

170–A. Glaciation in Alaska, by S. R. Capps. 1932. pp. 1–8, illus., maps (plane, 1:5,000,000).

182. The Tertiary flora of Alaska, by Arthur Hollick, with a chapter on the geology of the Tertiary deposits, by P. S. Smith. 1936. 185 pp., illus., map (plane, 1:5,000,000).

BULLETINS:

442–B. The preparation and use of peat as fuel, by C. A. Davis. 1910. pp. 101–132.

442–J. Alaska coal and its utilization, by A. H. Brooks. Reprinted 1914. pp. 47–100.

480–C. Geologic features of Alaskan metalliferous lodes, by A. H. Brooks. 1911. pp. 43–93, illus.

649. Antimony deposits of Alaska, by A. H. Brooks. 1916. 67 pp., illus., map (plane, 1:5,000,000).

776. The Mesozoic stratigraphy of Alaska, by G. C. Martin. 1926. 493 pp., illus.

836–C. Surface water supply of southeastern Alaska, 1909–30, by F. F. Henshaw. 1933. pp. 137–218, illus.

857–B. Past placer-gold production from Alaska, by P. S. Smith. 1933. pp. 93–98.

910–A. Mineral industry of Alaska in 1937, by P. S. Smith. 1939. pp. 1–113, illus. Other volumes in this series have been issued for each year since 1904. The more recent of these are 897–A, 1936; 880–A, 1935; 868–A, 1934; 844–A, 1931; 836–A, 1930.

WATER-SUPPLY PAPERS:

314. Surface water supply of Seward Peninsula, by F. F. Henshaw and G. L. Parker, with a sketch of the geography and geology by P. S. Smith and a description of methods of placer mining by A. H. Brooks. 1913. 317 pp., illus., map (T, 1:500,000).

342. Surface water supply of the Yukon-Tanana region, by C. E. Ellsworth and R. W. Davenport. 1915. 343 pp., illus., map (T, 1:250,000).

345–F. The discharge of the Yukon River at Eagle, by E. A. Porter and R. W. Davenport. 1915. pp. 67–77, illus.

372. A water-power reconnaissance in south-central Alaska, by C. E. Ellsworth and R. W. Davenport. 1915. 173 pp., illus.

418. Mineral springs of Alaska, by G. A. Waring. 1917. 114 pp., illus.

OTHER REPORTS

PROFESSIONAL PAPERS:

41. Geology of the Central Copper River region, Alaska, by W. C. Mendenhall. 1905. 125 pp., illus., maps (GT and T, 1:250,000, relief, about 1:760,000).

64. The Yakutat Bay region, Alaska, by R. S. Tarr and B. S. Butler. 1909. 183 pp., illus., map (GT, about 1:317,000).

70. The Mount McKinley region, Alaska, by A. H. Brooks and L. M. Prindle. 1911. 234 pp., illus., maps (GT and T, 1:625,000, and T, 1:250,000).

95–D. An ancient volcanic eruption in the upper Yukon Basin, by S. R. Capps. 1916. pp. 59–64, illus.

109. The Canning River region of northern Alaska, by E. de K. Leffingwell. 1919. 251 pp., illus., maps (GT and T, 1:250,000; plane, 1:125,000 and 1:1,000,000).

BULLETINS:

247. The Fairhaven gold placers, Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., illus., maps (T and GT, 1:250,000).

278. Geology and coal resources of the Cape Lisburne region, by A. J. Collier. 1906. 54 pp., illus., map (GT, about 1:800,000).

314–D. Reconnaissance on the Pacific coast from Yakutat to Alsek River, by Eliot Blackwelder. 1907. pp. 82–88.

BULLETINS—Continued.

328. The gold placers of parts of Seward Peninsula, Alaska, by A. J. Collier, F. L. Hess, P. S. Smith, and A. H. Brooks. 1908. 343 pp., illus., maps (T and GT, 1:250,000).

335. Geology and mineral resources of the Controller Bay region, by G. C. Martin. 1908. 141 pp., illus., maps (GT and T, 1:62,500).

347. The Ketchikan and Wrangell mining districts, by F. E. and C. W. Wright. 1908. 210 pp., illus., maps (G, about 1:890,000, and GT, 1:250,000).

374. Mineral resources of the Kotsina-Chitina region, by F. H. Moffit and A. G. Maddren. 1909. 103 pp., illus., maps (GT and T, 1:250,000).

417. Mineral resources of the Nabesna-White River district, by F. H. Moffit and Adolph Knopf, with a section on the Quaternary, by S. R. Capps. 1910. 64 pp., illus., maps (GT and T, 1:250,000).

433. Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, by P. S. Smith. 1910. 234 pp., illus., maps (GT and T, 1:62,500).

443. Reconnaissance of the geology and mineral resources of Prince William Sound, by U. S. Grant and D. F. Higgins. 1910. 89 pp., illus., maps (G, 1:250,000, and GT, 1:21,120).

446. Geology of the Berners Bay region, by Adolph Knopf. 1911. 58 pp., illus., maps (GT and T, 1:62,500).

448. Geology and mineral resources of the Nizina district, by F. H. Moffit and S. R. Capps. 1911. 111 pp., illus., maps (GT and T, 1:62,500).

449. A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, by P. S. Smith and H. M. Eakin. 1911. 146 pp., illus., maps (GT and T, 1:250,000, and T, 1:500,000).

467. Geology and mineral resources of parts of the Alaska Peninsula, by W. W. Atwood. 1911. 137 pp., illus., maps (G, Mercator projection, T and GT, 1:250,000).

485. A geologic reconnaissance of the Iliamna region, by G. C. Martin and F. J. Katz. 1912. 138 pp., illus., maps (GT and T, 1:250,000).

498. Headwater regions of Gulkana and Susitna Rivers, with accounts of the Valdez Creek and Chistochina placer districts, by F. H. Moffit. 1912. 82 pp., illus., maps (GT and T, 1:250,000).

500. Geology and coal fields of the lower Matanuska Valley, by G. C. Martin and F. J. Katz. 1912. 98 pp., illus., maps (GT and T, 1:62,500, and GT, 1:250,000).

501. The Bonnifield region, by S. R. Capps. 1912. 64 pp., illus., maps (GT and T, 1:250,000).

502. The Eagle River region, southeastern Alaska, by Adolph Knopf. 1912. 61 pp., illus., maps (GT and T, 1:62,500).

520–K. Geologic investigations along the Canada-Alaska boundary, by A. G. Maddren. 1912. pp. 297–314.

525. A geologic reconnaissance of the Fairbanks quadrangle, by L. M. Prindle, F. J. Katz, and P. S. Smith. 1913. 220 pp., illus., maps (GT and T, 1:62,500 and 1:250,000).

532. The Koyukuk-Chandalar region, by A. G. Maddren. 1913. 119 pp., illus., maps (GT and T, 1:500,000).

534. The Yentna district, Alaska, by S. R. Capps. 1913. 75 pp., illus., maps (GT and T, 1:250,000).

535. A geologic reconnaissance of a part of the Rampart quadrangle, by H. M. Eakin. 1913. 38 pp., illus., maps (GT and T, 1:250,000).

536. The Noatak-Kobuk region, by P. S. Smith. 1913. 160 pp., illus., maps (GT and T, 1:500,000).

BULLETINS—Continued.

538. A geologic reconnaissance of the Circle quadrangle, by L. M. Prindle. 1913. 82 pp., illus., maps (GT and T, 1:250,000).

542–C. The McKinley Lake district, Alaska, by Theodore Chapin. 1913. pp. 78–80, illus.

576. Geology of the Hanagita-Bremner region, by F. H. Moffit. 1914. 56 pp., illus., maps (GT and T, 1:250,000).

587. Geology and mineral resources of Kenai Peninsula, Alaska, by G. C. Martin, B. L. Johnson, and U. S. Grant. 1915. 243 pp., illus., maps (GT, 1:250,000; T, 1:62,500 and 250,000).

605. The Ellamar district, by S. R. Capps and B. L. Johnson. 1915. 125 pp., illus., maps (GT and T, 1:62,500).

607. The Willow Creek district, by S. R. Capps. 1915. 86 pp., illus., maps (GT and T, 1:62,500).

608. The Broad Pass region, by F. H. Moffit and J. E. Pogue. 1915. 80 pp., illus., maps (GT and T, 1:250,000).

622–H. Mineral resources of the Lake Clark-Iditarod region, by P. S. Smith. 1915. pp. 247–271, map (G sketch, about 1:3,300,000); Quicksilver deposits of the Kuskokwim region, by P. S. Smith and A. G. Maddren. 1915. pp. 272–291, illus. Gold placers of the lower Kuskokwim, with a note on copper in the Russian Mountains, by A. G. Maddren. 1915. pp. 292–360, illus.

630. The Chisana-White River district, by S. R. Capps. 1916. 130 pp., illus., maps (GT and T, 1:250,000).

631. The Yukon-Koyukuk region, by H. M. Eakin. 1916. 88 pp., illus., maps (GT and T, 1:500,000).

655. The Lake Clark-central Kuskokwim region, by P. S. Smith. 1917. 162 pp., illus., maps (GT and T, 1:250,000).

662. See 662–C.

662–C. Mining on Prince William Sound, by B. L. Johnson. 1918. pp. 183–192. Copper deposits of the Latouche and Knight Island districts, Prince William Sound, by B. L. Johnson. 1918. pp. 193–220, map (G sketch, about 1:375,000).

662–D. The gold placers of the Tolovana district, by J. B. Mertie, Jr. 1918. pp. 221–277, illus., map (G, 1:250,000).

662–G. Lode deposits near the Nenana coal field, by R. M. Overbeck. 1918. pp. 351–362, map (sketch, about 1:410,000).

664. The Nenana coal field, Alaska, by G. C. Martin. 1919. 54 pp., maps (GT on township plats, 1:31,680).

667. The Cosna-Nowitna region, by H. M. Eakin. 1918. 54 pp., illus., maps (GT and T, 1:250,000).

668. The Nelchina-Susitna region, by Theodore Chapin. 1918. 67 pp., illus., maps (GT and T, 1:250,000).

675. The upper Chitina Valley, by F. H. Moffit, with a description of the igneous rocks, by R. M. Overbeck. 1918. 82 pp., illus., maps (GT and T, 1:250,000).

683. The Anvik-Andreafski region, by G. L. Harrington. 1918. 70 pp., illus., maps (GT and T, 1:125,000 and 1:250,000).

687. The Kantishna region, by S. R. Capps. 1919. 116 pp., illus., maps (GT and T, 1:250,000).

714–E. Mineral resources of the Goodnews Bay region, Alaska, by G. L. Harrington. 1921. pp. 207–228, map (G, 1:250,000).

733. The geology of the York tin deposits, by Edward Steidtmann and S. H. Cathcart. 1922. 130 pp., illus., map (GT, 1:250,000).

739–B. Mineral deposits of the Wrangell district, by A. F. Buddington. 1923. pp. 51–75, illus., map (G sketch, 1:500,000).

BULLETINS—Continued.

742. Chromite of Kenai Peninsula, by A. C. Gill. 1922. 52 pp., illus., map (GT, 1:250,000).
745. The Kotsina-Kuskulana district, by F. H. Moffit and J. B. Mertie, Jr. 1923. 149 pp., illus., maps (GT and T, 1:62,500).
754. The Ruby-Kuskokwim region, by J. B. Mertie, Jr., and G. L. Harrington. 1924. 129 pp., illus., maps (GT and T, 1:250,000).
755–D. The Cold Bay-Chignik district, Alaska, by W. R. Smith and A. A. Baker. 1924. pp. 151–218, maps (G, about 1:760,000 and 1:250,000).
773–D. Petroleum in Alaska Peninsula: Mineral resources of the Kamishak Bay region, by K. F. Mather. 1925. pp. 159–181, map (G, 1:250,000); The Cold Bay-Katmai district, by W. R. Smith, pp. 183–207, map (G, 1:250,000).
773–E. Geology and gold placers of the Chandalar district, Alaska, by J. B. Mertie, Jr. 1925. pp. 215–263, illus., map (G, 1:250,000).
783–D. The Nixon Fork country and Silver-lead prospects near Ruby, by J. S. Brown. 1926. pp. 97–150, illus., maps (G sketch 1:63,360, and G, 1:250,000).
789. The Iniskin-Chinitna Peninsula and the Snug Harbor district, by F. H. Moffit. 1927. 71 pp., illus., maps (GT and T, 1:62,500 and 1:250,000).
791. Geology of the upper Matanuska Valley, by S. R. Capps, with a section on the igneous rocks by J. B. Mertie, Jr. 1927. 92 pp., illus., maps (GT and T, 1:62,500).
792. See 792–C.
792–B. Geology of the Knik-Matanuska district, by K. K. Landes. 1927. pp. 51–72, map (G sketch, about 1:330,000).
792–C. The Toklat-Tonzona River region, by S. R. Capps. 1927. pp. 73–110, illus., map (G sketch, 1:500,000).
797. See 797–F.
797–E. Aerial photographic surveys in southeastern Alaska, by F. H. Moffit and R. H. Sargent. 1929. pp. 143–160, illus., map (plane, 1:250,000).
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SEDIMENTARY ROCKS

PRE-PALEOZOIC ROCKS

The oldest sedimentary rocks in Alaska that have been definitely distinguished as of pre-Paleozoic age have been called Birch Creek schist and occur in the central part of Alaska, especially in the Yukon-Tanana region. This does not indicate that no other pre-Paleozoic sedimentary rocks occur in the Territory, for some of the rocks that have been grouped under the general term "undifferentiated Paleozoic or older rocks" are of pre-Paleozoic age. The great difficulty in determining that any Alaska rocks are pre-Paleozoic is that there is only one small area in which Cambrian rocks, the lowest subdivision of the Paleozoic, are definitely recognized by their fossil content. This area is adjacent to the international boundary in the southeastern part of the Kandik district. As a consequence, all diagnoses of rocks anywhere in Alaska as of pre-Paleozoic age at this time must be referred to this rather remote area, with resulting uncertainties and difficulties of tracing relationships.

The term "Birch Creek schist" was originally applied by Spurr, as a result of his explorations in 1896, to highly metamorphic rocks in the vicinity of the Yukon River, especially in the Eagle and Fortymile districts. On the basis of general lithologic and structural similarity the term was gradually extended by later workers to include highly metamorphic rocks in widely separated parts of the Yukon Valley, until for a time it was used in interior Alaska almost automatically for any of the old metamorphic rocks. Through the later more intensive studies by Mertie it became apparent that many unlike units had thus been improperly covered by the term. Then followed a process of eliminating certain members heretofore called Birch Creek, so that the remainder should be definitely a unit of pre-Paleozoic age. This process of elimination was carried by Mertie to as advanced a stage in the Yukon-Tanana region as was practicable from the field data in hand, but he recognized that associated with the rocks of sedimentary origin were certain old igneous rocks that could not yet be separated from the schists in mapping. Thus, as now mapped the areas of pre-Paleozoic rocks in the Yukon region cover some areas that are formed of old igneous rocks. This does not, however, annul the intention that the term and color used on the map are meant to cover only areas in which pre-Paleozoic sediments occur and that, were adequate data at hand, the formation indicated would include no igneous rocks.

In the Yukon-Tanana region wherever seen these rocks are typically schistose and include several different lithologic phases, which ultimately will probably form the basis for more detailed subdivisions. By far the most common types are quartzite, quartzitic schist, quartz-mica schist, and mica schist. Graphitic schist and calcareous schist have also been recognized and appear to be more characteristic of the upper part of the formation. These rocks have been subjected to profound mountain-building processes, probably during several different periods, so that they exhibit many secondary structural features induced by the diastrophism. In addition they have been intruded by igneous rocks, some of which were as late as the Tertiary, so that in places they show pronounced contact metamorphism as well. These processes have varied so greatly in different parts of the region that in different areas the rocks that may have originally been identical now display very diverse features. As a whole, it may be said that throughout the area occupied by the Birch Creek schist in the Yukon-Tanana region the rocks show few recognizable features of original structure and that instead only secondary or later-formed characteristics are conspicuous.

Inasmuch as the Birch Creek schist is the oldest formation now known in the region, its actual base has not been seen, and its complexity of structure precludes precise determination of the thickness even of the strata that are involved in the parts that have been studied in some detail. Under these conditions it is obviously impossible to make more than an indefinite surmise as to the total thickness of the formation. It is apparent from the field evidence, however, that the strata belonging in this unit have a thickness of at least several thousand feet and perhaps of many thousand feet.

On the geologic map of Alaska (pl. 1) the only other area in which sedimentary beds of pre-Paleozoic age have been definitely designated as such is the region on the northern flanks of the Alaska Range, extending eastward from the Kantishna district to and beyond the Tok River, in the eastern part of the Tanana River Valley. The probable correlation of the rocks in this belt with those of the typical Birch Creek schist in the Yukon-Tanana region has long been recognized, and these rocks have for many years been called by the same formation name. For a long time, however, the fact that any of these old rocks were pre-Paleozoic was not determined, and in general they were assigned only to pre-Ordovician time. With the determination of a pre-Paleozoic age for these schists in the type area in the vicinity of the Yukon, it now seems warranted to extend that age assignment to these rocks in the Kantishna-Tok area. This correlation seems well justified because, as will be seen from the map, the areas of highly metamorphic rocks north of the Tanana River are almost directly traceable into the rocks in question south of the river and, furthermore, because the relation of the rocks in this southern belt to the oldest fossiliferous rocks yet recognized near them—those of Silurian age—shows that they long antedated the Silurian period. Throughout this southern belt the rocks have remarkably uniform general characteristics, though in detail many different specific types are represented. As in the type area, the rocks are all highly schistose and are in general rather quartzose, though some calcareous members form subordinate parts of the sequence. Owing to the lack of detailed studies of the distribution of these rocks in the field, the area they are shown as occupying on the map includes some intrusive and extrusive igneous rocks that are intimately associated with the sedimentary beds. The intrusive rocks must necessarily be younger than the rocks they intrude, though whether that difference is great enough to place them in an entirely different system is not known. Possibly the effusive rocks may in part be contemporaneous with the sedimentary rocks, but verification of that surmise must necessarily await more detailed studies.

Although these are the only areas in Alaska where sedimentary rocks that are now definitely assigned to a pre-Paleozoic age are known to crop out, there are several other areas where it is suspected that rocks formed during pre-Paleozoic time may occur. On plate 1 these other areas have not been specifically indicated but have been included with those represented as containing undifferentiated Paleozoic or older rocks. There are six principal areas where more complete and detailed work is likely to disclose the presence of these old rocks—namely, the Wales and Ketchikan districts of southeastern Alaska; the eastern part of the tract between the Yukon and Tanana Rivers, the Cosna and Ruby districts, and the Dall and Tozi districts, of the Yukon region; the Kobuk, Alatna, and Wiseman districts of the northwestern Alaska and Yukon regions; and the Seward Peninsula region.

In the Wales and Ketchikan districts the lowest member of the stratigraphic sequence is a series of highly metamorphic rocks of considerable variety of composition and structure. The original characters of the rocks have been in large measure destroyed by subsequent metamorphism brought about both by mountain-building forces and by proximity to great igneous intrusive masses. These rocks form part of a complex that was designated the Wales group by Brooks, as a result of his field investigations in 1901 in the Ketchikan district, and this name was retained by Buddington and Chapin, although they considerably modified the limits of distribution and the contents of the group. No direct evidence is available as to the age of the lower members of this group, but some of them are definitely older than the nearby Ordovician beds, though some of the higher members may be as young as Devonian. Obviously, there is no good reason why the beds that are known to be of pre-Ordovician age might not indeed also be pre-Paleozoic.

In the eastern part of the Yukon-Tanana region is a thick sequence of old sedimentary rocks which Mertie has described under the name "Tindir group" (pl. 4, *B*). The rocks in the typical area are practically unmetamorphosed and include dolomite, limestone, shale, slate, quartzite, diabase, and basalt of greenstone and hematitic habit. This group is divisible into four distinct lithologic units, and doubtless further field work will show that the different units differ among themselves in age. All that can be definitely stated at this time as to age of these rocks is that, so far as now known, all the rocks are certainly older than Upper Cambrian and that there is apparently a marked stratigraphic hiatus between the top of the Tindir group and the known Middle Cambrian formation in the vicinity of the Tatonduk River. On the basis of his observations Mertie [2] sums up the present state of knowledge regarding the age of the Tindir group as follows:

> Although this evidence is too weak to justify the definite appellation pre-Cambrian for the Tindir group, it does justify the designation pre-Middle Cambrian, and the writer is inclined to the opinion that these rocks are probably of Algonkian age.

It should be noted in this connection that even if the Tindir group should ultimately be assigned to a pre-Paleozoic age, the lesser degree of diastrophism it appears to have undergone would indicate that it is probably younger than the typical Birch Creek schist, which is also pre-Paleozoic.

[2] Mertie, J. B., Jr., The Tatonduk-Nation district, Alaska: U. S. Geol. Survey Bull. 836, p. 392, 1933.

In the Cosna-Ruby region and the Kaiyuh Hills there are extensive areas of metamorphic rocks whose exact age equivalence has not been closely determined (pl. 4, *A*). Lithologically some of the members are highly metamorphosed schists, quartzites, and phyllites undistinguishable in appearance from some of the members of the pre-Paleozoic sequence in the typical area in the Yukon region. In general the older of these beds have exceedingly complex secondary structure, and their original features have been almost if not entirely obliterated by the diastrophism to which they have been subjected. Many of the members exhibit features due to rock flowage, evidently under a thick cover of overlying rocks. In the Cosna district, according to Eakin, these schists and quartzites are certainly of pre-Ordovician age, as they are overlain unconformably by limestone containing clearly diagnostic Ordovician fossils. Farther west in the Ruby district the absence of fossiliferous rocks as old as Ordovician prevents as close dating of the older metamorphic rocks. However, after weighing all the evidence available Mertie [3] reached the following conclusion:

> It is believed, therefore, that the metamorphic rocks of the Ruby-Poorman area are mainly of Paleozoic age but contain possibly some infolded rocks that may be comparable in age with the Birch Creek schist.

Until more discriminative field work is done, however, it would be going far beyond the available facts to do more than point out the likelihood that rocks of pre-Paleozoic age may occur in these districts.

In the enormous tract of country lying north of the Yukon between the settlements of Beaver and Tanana only exploratory surveys have been carried on, so that the geology has been only sketchily determined. These surveys have indicated, however, that considerable areas in this tract are occupied, as shown on the geologic map (pl. 1), by metamorphic rocks that are of Paleozoic age or older. According to Maddren,[4] who crossed the eastern part of this area, the rocks are dominantly quartz-mica schist, schistose quartzite, phyllite, slate, amphibolitic schist, and highly crystalline limestone. In agreement with the earlier Survey explorers—Mendenhall, Schrader, and Spurr—he accepted the general correlation of these rocks with the Birch Creek schist, but, also following them, he did not go further than suggest a pre-Ordovician age for the formation, though the type section of that formation is now accepted as pre-Paleozoic. Eakin, in tracing the continuation of this same general belt of rocks toward the west, recognized the same general lithologic and structural features in some of the rocks, though others with which they were so closely associated that they could not be mapped separately showed features which seemed to indicate that they were younger. Eakin's general conclusions regarding certain of these rocks [5] were summed up by him as follows:

> The apparently older schists may be generally equivalent to the Birch Creek schist of the Yukon-Tanana region and to the older 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.

Extending westward from the East Fork of the Chandalar River in a somewhat irregular strip, nearly to the mouth of the Kobuk River, is an area shown on plate 1 as undifferentiated Paleozoic or older sediments. Evidence as to the age of most of the rocks that form this belt is so indefinite that the general noncommittal designation given to them is about as far as the facts in hand justify one in attempting to go. At the heads of the Chandalar and Koyukuk Rivers there is evidence that these rocks unconformably underlie rocks that contain Silurian fossils, and on the John River and the Alatna River and apparently in the Kobuk area they seem to underlie limestones that have been correlated with the Silurian on lithologic and stratigraphic grounds. The rocks are all highly altered through dynamic metamorphism and consist of schists that differ greatly in composition from place to place but are characteristically highly micaceous and generally very quartzose, though calcareous facies are by no means uncommon. The schists have been strongly deformed, and the original features of the rocks have been almost completely altered or obliterated. As a consequence, no close estimates as to the thickness of the formation can be given, but apparently it is to be measured in thousands of feet, if not tens of thousands. The great thickness of these beds and the diastrophism that they have undergone prior to the laying down of the first overlying formation whose age is determinable from fossil evidence—the Silurian—give ample basis for entertaining the belief that a much longer time interval must have ensued between the deposition of these older rocks and the Silurian limestone than would be represented by the early part of the Paleozoic era. For these reasons it seems not unlikely that at least a part of these old metamorphic rocks may have been laid down in pre-Paleozoic time.

In Seward Peninsula the oldest known fossiliferous rocks are of Ordovician age, though at one time fossils that were then thought to be Cambrian were reported. Underlying these rocks, which are relatively but little deformed, are others which have been highly metamorphosed through dynamic processes and in which practically all their original characteristics have been obliterated and replaced by secondary structural features. These metamorphic rocks include many dif-

[3] Mertie, J. B., Jr., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. 754, p. 17, 1924.

[4] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pp. 34–38, 45–49, 1913.

[5] Eakin, H. M., The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 631, p. 31, 1916.

ferent lithologic varieties, and some of the different kinds show structural differences that strongly suggest rocks of distinctly different ages. In fact, in the detailed work that was done in the Nome area Moffit distinguished an older group which he designated the Kigluaik group (pl. 5) and a younger one for which, following the already established usage of Brooks, Mendenhall, Collier, and others, he retained the name "Nome group." Regarding the age of the lower or Kigluaik group Moffit[6] writes:

> The basal beds of the Kigluaik group are believed to be among the oldest strata exposed on Seward Peninsula and possibly in Alaska, though the rocks themselves contain no fossils to support this belief, and it is not now susceptible of proof,

and later in the same report Moffit specifically calls attention to the fact that, although this group may be assigned to Paleozoic systems, there is nothing that would preclude regarding it as older, "possibly even in part pre-Paleozoic."

The Nome group, as defined by Collier in the revision of the early work in Seward Peninsula, is described as consisting of a great variety of rocks of different composition, structure, and age that probably ranged from Devonian to pre-Silurian. The group is subdivided into four more or less distinct units, the lower two of which are separated from each other by an unconformity and from the upper two by a possible unconformity. The upper of the two lower units is summarized by Collier[7] as consisting of various schists and phyllites, including quartz-chlorite schist, quartz-chlorite-albite schist, quartz-graphite schist, calcite, muscovite schist, thin limestones, etc. The lower member is described as graphitic quartzites and schists having probably a maximum thickness of less than 2,000 feet. Subsequent work in Seward Peninsula has disclosed much more complex relations and has raised considerable doubt as to the validity of this rather simple differentiation. Furthermore, no maps are available showing the distribution of these different units, so that, even if these distinctions were valid, they could not now be delineated on the geologic map. They do, however, serve to indicate that Seward Peninsula contains rocks that much antedate the Ordovician and that may prove on more detailed investigation to have been formed even earlier than the beginning of the Paleozoic.

In addition to these larger areas of rocks that, though not distinctly recognized as being pre-Paleozoic, may well include such rocks, there is in the vicinity of the Canning River, in northern Alaska, an area mapped as "undifferentiated Paleozoic and older sedimentary rocks" which possibly may contain rocks of pre-Paleozoic age. In the Canning River district Leffingwell found quartzite schists and related rocks which he called the Neruokpuk schist and assigned to pre-Carboniferous time. Although it is possible from this assignment that these rocks may be as old as pre-Paleozoic, that seems unlikely, because the structural features observed in them do not seem to have resulted from as complex diastrophism as that which produced those found in the rocks of known pre-Paleozoic age or their correlatives. Final decision in this matter, however, must await more detailed field investigation.

PALEOZOIC ROCKS

CAMBRIAN SYSTEM

Rocks of known Cambrian age are present in Alaska only in the extreme eastern part of the Territory, in the area adjacent to the international boundary north of the Yukon River (pl. 4, *D*). According to Mertie, who has studied in some detail the sequence in which these rocks are exposed, the known Cambrian rocks are divisible into four units which, from youngest to oldest, are as follows: A limestone of Upper Cambrian age, which grades without any distinct lithologic break into the Ordovician limestone; an upper plate of Middle Cambrian limestone; a thin formation of Middle Cambrian slate and quartzite; and a lower plate of limestone, also of Middle Cambrian age. Underlying these definitely Cambrian beds, but in such a manner that its relation to the overlying beds is not unequivocally determinable, is the Tindir group, which, on the whole, shows structural features essentially similar to those of the Cambrian beds. The definitely Cambrian beds have been broadly deformed and somewhat fractured by the earth movements to which they have been subjected subsequent to their deposition, but on the whole in this particular area they have not been metamorphosed appreciably and they still retain many of their original characteristics unaltered. Apparently this particular area in central eastern Alaska escaped in large measure some of the intensive diastrophism that affected large areas of even the younger rocks in other parts of the Territory, and thus it has preserved almost unchanged the relics of this early period. A continuation of these Cambrian rocks eastward into Canada has been recognized by the geologists of the Canada Geological Survey, and it is not unlikely that in some of the now unmapped areas to the north of the known Cambrian occurrences these beds may be brought to the surface again by folding and faulting.

The apparent absence of recognized Cambrian rocks in other parts of Alaska is probably not to be attributed to their real absence so much as to the geologists' inability to distinguish them from other rocks with which they may be associated or to the fact that they occur in areas that have not yet been explored. On the whole, however, it is believed that Cambrian rocks do not now form extensive areas at the surface anywhere within

[6] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, p. 23, 1913.

[7] Collier, A. J., The gold placers of parts of Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 328, p. 65, 1908.

the Territory, though such a belief is entitled to hardly more weight than any other relatively unsupported guess.

Other areas in which Cambrian rocks may occur have been included in those mapped as occupied by undifferentiated Paleozoic or older rocks. In the section on pre-Paleozoic rocks some discussion has been given of formations whose age has not been more closely identified than that they are earlier than some of the Paleozoic systems, and it has been shown that several of these formations are believed to be really assignable to even pre-Paleozoic time. It must be admitted, however, that the rocks here under consideration have not yet yielded evidence to warrant their assignment to so early a time. Thus all that is really known about the age of the Tindir group in the Tatonduk district is that it is earlier than Middle Cambrian, so that it may be in part Lower Cambrian as well as in part pre-Paleozoic. The Nome group, in Seward Peninsula, which is assigned in general to pre-Ordovician time, may in part contain Cambrian beds. So too in southeastern Alaska the part of the Wales group of the Ketchikan district that is regarded as pre-Ordovician may contain unrecognized Cambrian beds. But while conscious of these possibilities, the writer has the distinct impression that in most of the areas that have been already discussed, with the exception of Seward Peninsula, there is more likelihood than not that the bulk of these pre-Ordovician or even pre-Middle Cambrian formations are in general also pre-Paleozoic.

However, it is believed that in other areas that are shown on the geologic map (pl. 1) as occupied by undifferentiated Paleozoic or older sedimentary beds Cambrian sedimentary rocks might be found, if more critically searched for and intensively studied. One of the areas of this sort is in the western part of Seward Peninsula, near York, contiguous to the areas of known Ordovician rocks. In fact, from time to time in the past some of the fossil collections from that area have been regarded, on the scanty data then available, as Cambrian. A reexamination of all the collections from this whole district was undertaken by Edwin Kirk, who reached the conclusion that none of the fossils should be assigned to the Cambrian, an opinion in which C. D. Walcott and E. O. Ulrich concurred. Although it is necessary, therefore, to admit the absence of direct evidence from fossils of the Cambrian age of any of the rocks in this area, there are stratigraphic grounds for not abandoning this possibility. These grounds are as follows: The lowest known Ordovician rocks are limestones practically free of all other kinds of sediments. Underlying these limestones are a series of dark-colored to glistening black graphitic slates or phyllites, usually without prominent bedding planes. The precise relation between these different rock types is not evident, though apparently in places there is little evidence of marked structural discordance between the two except where it is obviously due to more recent faulting. However, the studies of Steidtmann and Cathcart seem to indicate a marked break between the periods of deposition of the two formations, because basalts and gabbros have been intruded into the slates but not into the limestones. How long a time is represented by this break is indeterminable from the facts at hand.

Steidtmann and Cathcart evidently were unable to reach a decision in the matter, for in the legend of the map accompanying their report they left an opening for a great disparity in age of the two formations by assigning the black slate to the Cambrian or pre-Cambrian. Knopf, however, who had earlier studied the region and was on record as regarding the two lithologic units as conformable, evidently believed that the time interval between the two formations was slight. The evidence from the intrusives does not seem incontrovertible, but neither does the validity of the conclusion that the slates stratigraphically underlie the limestones seem to the writer to be proved beyond cavil. In fact, the wide occurrence of clastic brown tourmaline in the slates, as reported by Knopf,[8] would lead to the question whether the slates are really as old as the early part of the Paleozoic, because the intrusion that seems to have introduced the tin minerals and consequently the tourmaline was at least Mississippian or later. In view of these uncertainties it has seemed advisable to assign these rocks to the rather noncommittal group of undifferentiated Paleozoic or older sedimentary rocks, though recognizing that the present weight of evidence would seem to point to a Cambrian or earlier age.

In addition to these so-called slates near York there are other rocks throughout Seward Peninsula whose age has by no means been determined so closely as to exclude the possibility that they were formed within the time limits of the Cambrian period. In the eastern part of the Yukon region the Cambrian was found to pass without stratigraphic discordance or lithologic break into the Ordovician. This same condition is likely to prevail in other areas also, and consequently it seems probable that more intensive examination of parts of the sequence in Seward Peninsula now mapped as Ordovician might prove that some of it was formed during the Cambrian. There is also a strong possibility that some of the less metamorphosed rocks in Seward Peninsula that now, in the lack of adequate evidence for separation, have been placed together as members of the Nome group and are shown on the geologic map (pl. 1) as undifferentiated Paleozoic or older, may eventually be separable from the more highly metamorphosed rocks discussed in an earlier section, which are probably of pre-Paleozoic age. In that case possibly some of these members may be of Cambrian

[8] Knopf, Adolph, Geology of the Seward Peninsula tin deposits, Alaska: U. S. Geol. Survey Bull. 358, p. 11, 1908.

age, though proof of that assignment will be difficult to demonstrate if it cannot be supported by direct evidence from fossils.

ORDOVICIAN SYSTEM

The Ordovician period is now known to be widely represented in Alaska from the extreme southern part, in the Ketchikan and Wales districts, to the extreme western part of Seward Peninsula, in the York district. Undoubtedly, as more of the unsurveyed area is explored and as more critical and detailed investigations are made in some of the areas occupied by rocks of early Paleozoic age, additional places where these rocks occur will be discovered. The larger of the known areas of Ordovician rocks are indicated on the geologic map (pl. 1). They are distributed through the Wales and Kupreanof districts of southeastern Alaska, the Porcupine, Kandik, Eagle, and Ruby districts of the Yukon region, the McGrath district of the Kuskokwim region, and the York and Kougarok districts of Seward Peninsula. There are other areas which contain rocks that probably belong to this system but which are too small to be correctly represented on the map or in which the distribution of the Ordovician rocks has not been determined with sufficient accuracy to permit graphic representation. Areas of this sort have been included within the boundaries of undifferentiated Paleozoic or older rocks and are discussed in some detail at the end of this section on the Ordovicion system.

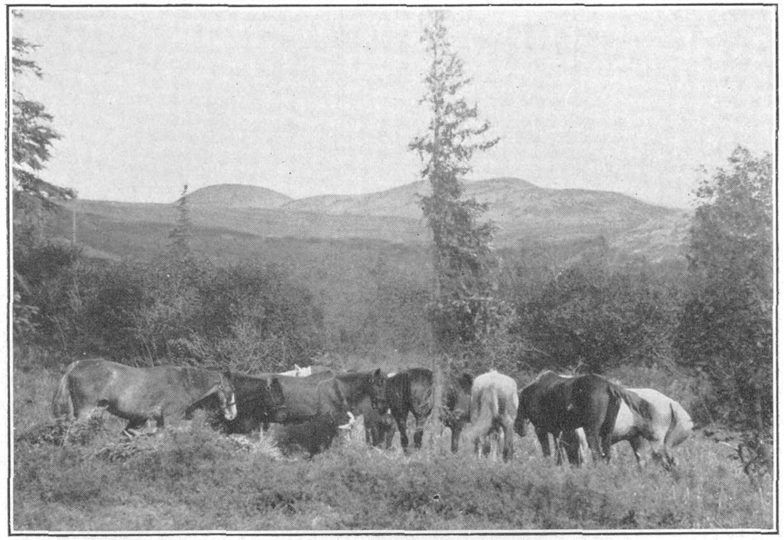
SOUTHEASTERN ALASKA

In southeastern Alaska the principal Ordovician localities now known may be grouped into two principal areas—one including scattered localities on Prince of Wales Island and the nearby islands and the other a tract from 10 to 20 miles wide extending almost uninterruptedly in a southeasterly direction the entire length of Kuiu Island from Security Bay on the northwest coast to Point St. Albans on the southeast coast. On Prince of Wales Island the known Ordovician rocks are best displayed on the west coast in the vicinity of Klawak and adjacent islands in the Gulf of Esquibel and Bucareli Bay and in the vicinity of Tokeen and the nearby islands. On the east coast of Prince of Wales Island the most extensive exposures occur west of Kashavarof Passage and in the vicinity of Tolstoi. According to Buddington the Ordovician sequence in all these places consists dominantly of a thick series of graywacke beds with associated slate and locally some andesitic volcanic rocks. Less commonly conglomerate, grit, limestone, black chert, and quartzite form part of the sequence. Such fossils as have been found in these rocks are mainly graptolites that are now assigned to the Lower and Middle Ordovician, although originally a number of the collections were regarded as probably Silurian. The relation of the Ordovician to the overlying rocks is nowhere clearly demonstrable, because usually faulting or crushing has masked the immediate contact zone. The absence of a recognized Upper Ordovician fauna in these rocks may be interpreted as indicating a marked time break between them and the overlying Silurian, but this interpretation is by no means incontrovertible, for everywhere in the section fossils are scarce, and those that have been found were collected from beds at a considerable distance below the known top of the section. As neither the top nor the bottom of the rocks of this system has been determined in this area the thickness of the sequence cannot be measured, but apparently several thousand feet of beds are included. Structurally the rocks have been much deformed on a large scale and in places minutely plicated and brecciated, and rarely even schistosity has been developed. Details of structure are usually indeterminable, because isoclinal folding and complex faulting of both normal and overthrust types have greatly complicated the relations.

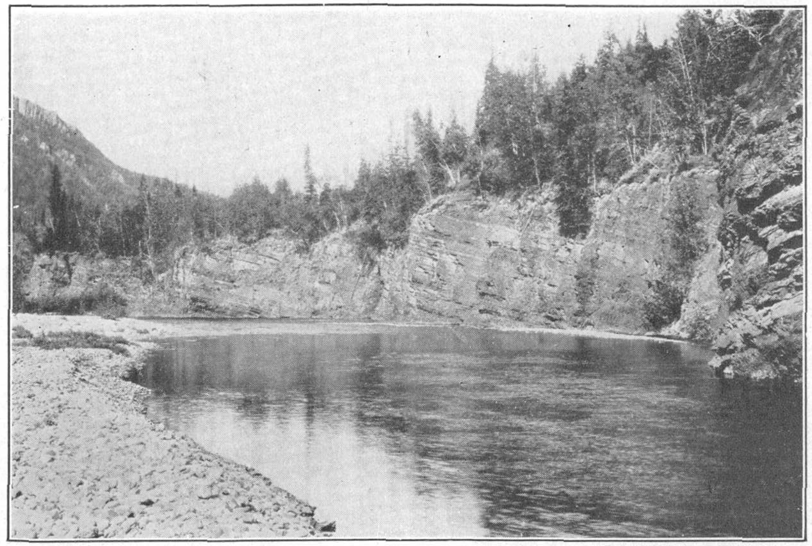
YUKON REGION

In the Kandik district of the Yukon region rocks representing the lower and middle epochs of the Ordovician period have been so identified from the fossils they contain, as well as from their stratigraphic relations. In places the lower part of the Ordovician sequence is composed of limestone that so closely resembles the Upper Cambrian limestone of the Kandik district that the two cannot be differentiated except on paleontologic evidence. At other places in this district the Upper Cambrian limestone appears to be conformably overlain by dark-gray to black thin-bedded siliceous slates and cherts carrying a fauna, mostly bryozoan, of high Lower Ordovician to low Middle Ordovician age. The area in which the Ordovician rocks were seen in most detail is probably only a part of the area in the vicinity of the 141st meridian in which related rocks occur, for the geologists of the Canada Geological Survey have referred to various localities east of the international boundary at which comparable rocks were found, and Kindle[9] examined outcrops of Ordovician rocks in Alaska in the Porcupine River Valley, to the north. In the Porcupine Valley the only Ordovician fossils collected by Kindle were obtained in the bluffs of the lower Ramparts from a blue-gray limestone that has an estimated thickness of 600 feet. Part of the limestone is oolitic. Other rocks occur in the vicinity of this limestone, but in the absence of fossils it has not been possible to determine whether or not they are, at least in part, of Ordovician age. The limestone in which the fossils were found has been assigned to the Middle Ordovician and is considered as representing a horizon that is about the equivalent of the Mohawkian in the States. The relations of this limestone to the

[9] Kindle, E. M., and Brooks, A. H., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, pp. 271–272, 1908.

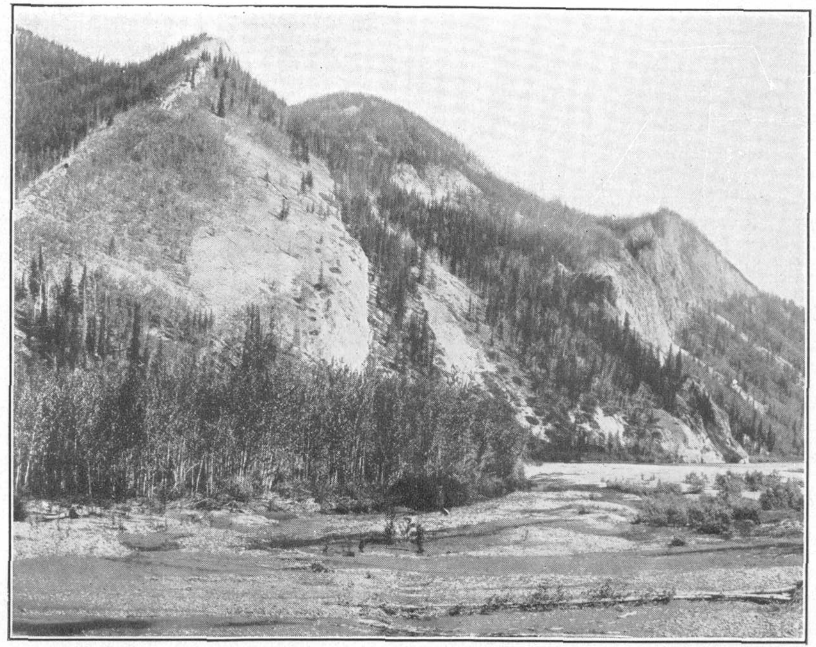


A. TYPICAL TOPOGRAPHY OF UPLANDS IN AREA OF UNDIFFERENTIATED PALEOZOIC OR OLDER SCHISTS IN THE KAIYUH HILLS IN CENTRAL ALASKA.

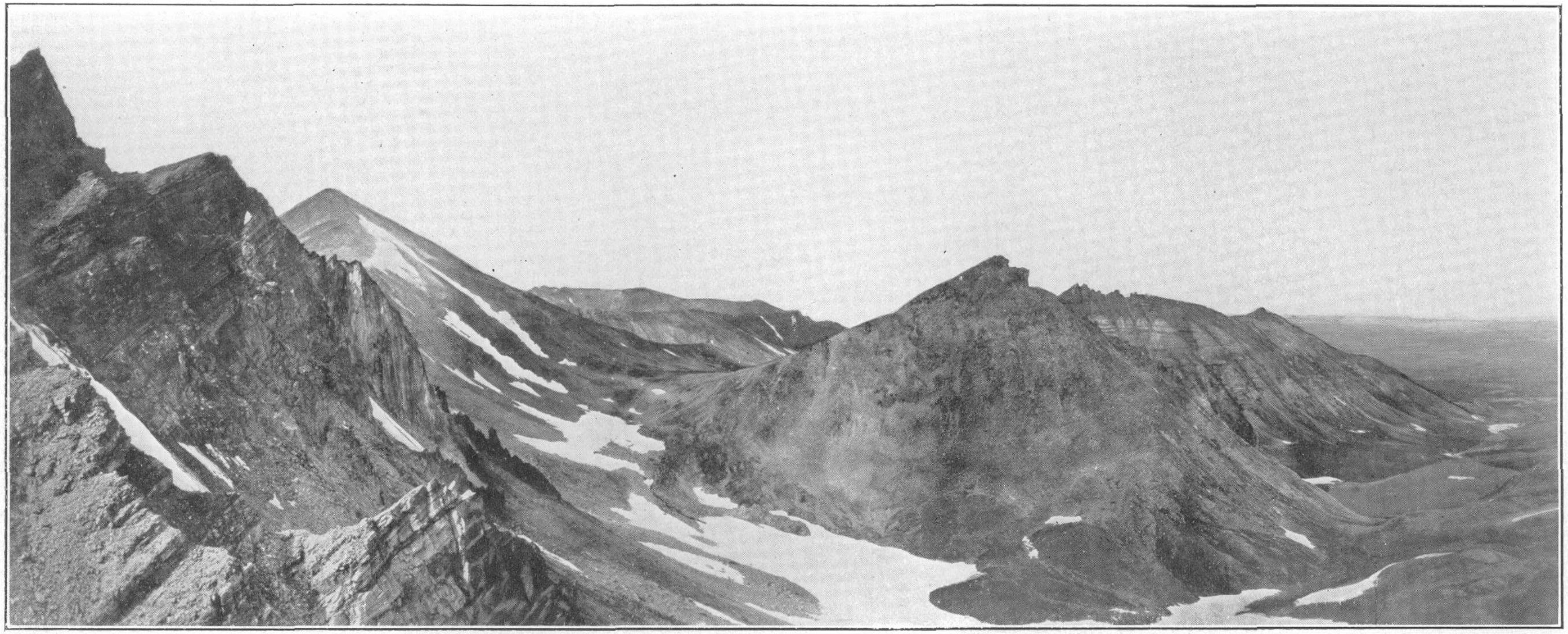


B. RED BEDS OF THE TINDIR GROUP, PRESUMABLY OF PRE-PALEOZOIC AGE, ON TATONDUK RIVER A FEW MILES WEST OF THE INTERNATIONAL BOUNDARY.

C. BLOCK OF SKAJIT LIMESTONE, OF SILURIAN AGE, CONTAINING MANY FOSSIL SHELLS, NEAR HEADWATERS OF NORTH FORK OF CHANDALAR RIVER.



D. EXPOSURES OF MIDDLE CAMBRIAN LIMESTONE ON TATONDUK RIVER A SHORT DISTANCE NORTH OF YUKON RIVER.



BIOTITE SCHISTS AND HIGHLY METAMORPHIC ROCKS OF THE KIGLUAIK GROUP, OF EARLY PALEOZOIC OR OLDER AGE, IN KIGLUAIK MOUNTAINS OF SEWARD PENINSULA.

underlying rocks are also unknown, but Brooks and Kindle were inclined to believe that the limestone was separated from them by an unconformity, as on the whole the structure of the limestone showed less disturbance through mountain-building forces than the underlying rocks which are, in general, schistose and highly deformed. The statement that the Ordovician limestone is less deformed than the older schists should be taken in a relative sense only, for Kindle refers to one of the Ordovician outcrops in the section studied by him as having beds standing vertical in the upper part of the cliff, above various contorted beds at the base of the cliff.

In the White Mountains of the Preacher district Ordovician rocks have been reported, but they occupy so small a tract that it could not be appropriately shown on plate 1. At this place a thin layer of volcanic tuff lying immediately below the Silurian limestones and on top of extrusive rocks carries a Middle Ordovician fauna. Below the volcanic rocks is a succession of black slates and shales of Lower Ordovician age, which give place below to more and more highly metamorphosed rocks. The higher shales contain fossils of known Lower Ordovician age, but it is impossible to detect the stratigraphic break that marks the base of those rocks and the top of the underlying strata, so that these Ordovician rocks, as well as the younger of the underlying formations, have not been separated out but have been grouped together as part of the undifferentiated Paleozoic and older sedimentary beds.

In the Ruby district of the Yukon region and the McGrath district of the Kuskokwim region Ordovician rocks have been recognized in the country adjacent to the Sulukna River, a tributary of the Nowitna, and in the hills near the Nixon Fork mines, adjacent to the Nixon Fork, a tributary of the Kuskokwim River. The Ordovician rocks in the Ruby district are described by Eakin as occupying a large area on the headwater portion of the Sulukna River and on the divide between that stream and the Sethkokna River. So far as determined by Eakin, the group consists entirely of carbonate rocks without any notable admixture of siliceous or argillaceous sediments. The beds include both calcium carbonate and magnesium carbonate rocks and mixtures of the two, though the pure calcium limestones form by far the larger part of the sequence. The dolomitic phases appear to be more abundant toward the base of the group. The purer limestones are mostly dark gray on fresh fracture but weather to a uniform light gray on exposed surfaces. The dolomitic phases are usually brownish yellow but become somewhat lighter colored on weathering.

The stratigraphy of the group has not been completely worked out, so that its thickness has not been determined closely. However, measurements indicate that the aggregate thickness of the rocks now assigned to the Ordovician can hardly be less than 6,000 feet and is more likely as much as 8,000 feet. On the whole, the structure of the Ordovician rocks in this area is relatively simple, consisting usually of broad, open folds. At a few places, however, the beds stand vertical, but no overturned folds were recognized. Throughout the area occupied by the Ordovician in this district the rocks have been subjected to faulting, some of which resulted in great dislocation, though most of it seems to have caused only small displacement. This sequence of carbonate rocks rests unconformably on schists whose age has not been determined closely, but which may be as old as pre-Paleozoic and on the geologic map (pl. 1) have been shown as undifferentiated Paleozoic or older. The top of this system has not been determined, but the fact that the next younger formation that has been recognized as overlying it is of Devonian age suggests that the top of the Ordovician, as well as all of the Silurian, may be lacking in this district.

More or less in direct southward continuation of the belt of Ordovician sedimentary beds of the Ruby district, just described, are the exposures of similar rocks in the McGrath district, in which collections of fossils of comparable age have been made. In this southern area, however, the separation of Ordovician, Silurian, and Devonian rocks has not yet been satisfactorily made, so that it has not been practicable to distinguish on the map the area occupied by the Ordovician by its distinctive color, but instead it has been necessary to group these rocks with those of later age as undifferentiated Paleozoic or older rocks. This assemblage of early Paleozoic rocks consists in the main of a thick sequence composed dominantly of limestones and other carbonate rocks that show considerable variety in appearance and lithologic composition. In the places where most of the collections of Ordovician fossils were made the limestone is usually bluish gray on fresh fractures and weathers to a dull white or gray. Its beds are as a rule only moderately thick, but massive beds 20 to 200 feet thick occur and form rugged peaks that are conspicuous landmarks. The structure of the group of limestones as a whole is complex, and nearly everywhere the beds are so sharply folded that in places they are overturned. Great faults as well as many of lesser size have produced notable structural displacements and complicated the stratigraphic relations of these rocks, not only to themselves but also to adjacent beds. The combined thickness of this group of limestones is evidently very great, though precise measurements are lacking. Brown [10] states as his conclusion that the series must be at least 5,000 to 7,000 feet thick and may well be much more.

[10] Brown, J. S., The Nixon Fork country: U. S. Geol. Survey Bull. 783, pp. 102–105, 1926.

KUSKOKWIM REGION

In the course of explorations in 1903 across the Alaska Range and along its northern flanks, Brooks' party found Ordovician fossils near the Tatina River; a tributary of the South Fork of the Kuskokwim River, and to the northeast in the valleys of the Jones and Dillinger Rivers. Rocks which Brooks correlated with these definitely Ordovician beds were seen at a number of points along his route, and to all of these he gave the definite name "Tatina group" and assigned the entire group to the Ordovician. Subsequent studies of part of the area seen in haste by Brooks have raised doubt as to the correctness of extending so far the correlation of the proved Ordovician rocks at the Tatina River. As a consequence, much of the area that was shown on Brooks' map as occupied by Ordovician rocks has on plate 1 been assigned to a less definite place in the stratigraphic section and designated as falling into the group of undifferentiated Paleozoic or older sedimentary rocks, and only a small incompletely defined area has been represented as occupied by rocks of Ordovician age. Doubtless, as the geology of the northern flank of the Alaskan Range is worked out in more detail, other Ordovician localities will be found and differentiated, for it is believed that this system has a widespread distribution in this part of Alaska.

The typical section on the Tatina River, as described by Brooks [11] consists of 1,000 to 1,500 feet of blue limestone locally sandy and carrying carbonaceous matter. The limestone occurs in layers from 1 to 20 feet thick that are interbedded with argillaceous and carbonaceous slates in beds that for the most part are not more than 1 foot thick, though in places they are 50 feet or more thick. These rocks are highly folded and contorted and in places have been intruded by later igneous rocks. Faults showing a wide range in the amount of displacement they effected have cut the formation and complicated its areal distribution and relations. In fact, in general the boundaries between the so-called Tatina rocks, as shown by Brooks' map, were almost everywhere fault contacts. Only three small collections of fossils have been obtained from these rocks, so that their position in the Ordovician is not clearly established, but the fossils indicate that the rocks from which they came may tentatively, at least, be assigned to the Middle Ordovician.

SEWARD PENINSULA

The most extensive area of Ordovician rocks in Alaska is in the western part of Seward Peninsula, where more than 2,000 square miles of the surface is composed almost exclusively of rocks of this system. Although it is possible that, because of the lack of detailed stratigraphic field studies, some younger rocks may be erroneously included in the area of the Ordovician rocks as mapped, there can be little doubt that on the whole this is unlikely, because practically all the collections of fossils that have been made at widely scattered points throughout that area have now been definitely assigned to the Ordovician. This correlation has not always prevailed, for many of the earlier collections were assigned to the Silurian period. A review of all these collections, as well as later ones, was made by Edwin Kirk, and it is on his determinations, which were published in detail in Steidtmann and Cathcart's report,[12] as well as on the other criteria from the field, that the present correlation rests. According to Kirk, both Lower and Upper Ordovician fossils are represented in these collections, though the stratigraphic studies were not carried out in the field in enough detail to enable the distinction of the two to be made on lithologic or other physical criteria. As thus mapped (pl. 1) the rocks forming the Ordovician system in Seward Peninsula consist dominantly of limestone—in many of the reports called the Port Clarence limestone. In their more characteristic and less metamorphosed phases the limestones are bluish gray on fresh fracture and weather to a lighter color, becoming almost white on exposure. In the western part of the area the original bedding planes are sufficiently well preserved to be readily evident. In this part the structure is relatively simple, and the rocks have been bent into rather broad, open folds. Here the rocks show little evidence of dynamic metamorphism, though locally the beds have been considerably altered through the metamorphism produced by the igneous intrusives that have been injected into them. The group has experienced some faulting, especially in the areas contiguous to other formations, so that neither the true bottom nor the top of the system has been recognized. Under these conditions no precise measurements of the total thickness of these rocks have been possible. Collier [13] indicates that in his opinion the system includes beds at least 5,000 feet thick, unless duplication of some of the section has been caused by unseen and unsuspected faults.

Elsewhere in Seward Peninsula are many other areas of limestone that from time to time in the past have been more or less definitely correlated under the name "Port Clarence limestone." It is by no means certain that some of these correlations are not still valid, but as it is now known that great limestones of Silurian, Devonian, and Carboniferous age also occur in Seward Peninsula, it has become evident that correlation on lithologic grounds alone in that area is especially hazardous. These other limestone areas

[11] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pp. 69–73, 1911.

[12] Steidtmann, Edward, and Cathcart, S. H., Geology of the York tin deposits, Alaska: U. S. Geol. Survey Bull. 733, pp. 23–29, 1922.

[13] Collier, A. J., and others, The gold placers of parts of Seward Peninsula: U. S. Geol. Survey Bull. 328, p. 73, 1908.

have therefore been given a less definite age assignment and placed in the undifferentiated Paleozoic or older rocks. This course became especially necessary because in these other areas many of the physical features of the limestones depart widely from those of the limestone in the area of known Ordovician age. Thus many of these other limestones show a high degree of alteration through dynamic metamorphism, and others are intimately interbedded with argillaceous and arenaceous sediments—conditions widely different from those in the western area, where changes due to dynamic metamorphism are practically absent and the beds are almost pure limestone. Obviously, these differences are not final bars to some of the suggested correlations, for, as is well known, different conditions prevailed in different parts of the area, but they do serve as cautionary signals to go slow in making correlations until these differences are satisfactorily accounted for. In the present state of our knowledge regarding the geology of Seward Peninsula we are not justified in ignoring this need for conservatism in assigning these numerous widely scattered limestones in central and eastern Seward Peninsula to any specific period.

Although nowhere else in Alaska are definite Ordovician beds known to occur, there are many places even outside the unexplored tracts where it is possible that sedimentary rocks of this system may be present. Such areas obviously would be restricted mainly to those that are shown on the geologic map, as occupied by undifferentiated Paleozoic or older rocks or those that are contiguous to the next older or younger formations. Sporadic occurrences of rocks of Ordovician age might crop out in unexpected places where local complex structural disturbance has profoundly affected the normal distribution of formations, because doubtless throughout extensive tracts the Ordovician rocks, although not appearing at the surface, in reality underlie the tracts, having been buried by younger beds.

SILURIAN SYSTEM

Rocks that are known to have been formed during the Silurian period have been recognized in different areas from the extreme southern part of the Territory, in the Wales district, to the extreme northwestern part, in the Noatak district of northern Alaska. In addition there are many places where, though the presence of Silurian rocks has not yet been proved, there is good reason to believe that they will be found if more thoroughly searched for in the course of more detailed examinations. The four principal regions in which Silurian rocks are now known are southeastern Alaska, the Yukon region, northern Alaska, and Seward Peninsula. The distribution of the known Silurian rocks in these regions is graphically represented on plate 1, so far as is compatible with the scale, except that those occurring on Seward Peninsula have not been separately mapped but have been included with the undifferentiated Paleozoic or older rocks. A brief description of these rocks in each region is given in the following pages.

SOUTHEASTERN ALASKA

In southeastern Alaska there are three main areas where the bedrock is dominantly of Silurian age. These areas, named from south to north, are Dall Island and adjacent areas, the northern part of Prince of Wales Island, and the Glacier Bay district. Between these larger areas, however, there are a number of smaller areas in which Silurian rocks crop out, so that it is evident that at one time representatives of this system must have covered practically all of what is now the southeastern Alaska region. According to Buddington these rocks range in age from early Silurian to at least as late as middle Silurian and probably even later, though no definitely recognized late upper Silurian fossils have yet been identified from this region. The base of the Silurian is probably separated from the older underlying Ordovician rocks by an unconformity, though this has by no means been proved, and the lithology of the rocks of the two systems is so similar that apparently there was no great break in the character of the sedimentation in the two.

The Silurian of southeastern Alaska, as it has been worked out by Buddington and Chapin, is divisible into four or possibly five more or less distinct lithologic types which are also distinguished by difference in age. At the base of the sequence is indurated graywacke with associated black slate and small amounts of conglomerate and limy beds. This member, whose thickness has not been determined, has the greatest areal extent on San Fernando, Dall, Lulu, and Noyes Islands, on Klakas Inlet, and in Glacier Bay. Lying above this member, and possibly separated from it by an unconformity, are andesite and andesite porphyry lava flows, conglomerate, and some associated graywacke, tuff, breccia, and limestone. The thickness of this member is estimated to be about 3,000 feet. It is well exposed on the Kashavarof Islands, Prince of Wales Island, El Capitan Passage, and Kuiu and Sumner Islands. Conformably overlying this member is a thick-bedded dense limestone about 3,000 feet thick in which are intercalated locally thick beds of conglomerate, thin-layered limestone, nodular shaly argillaceous limestone, and sandstone. The conglomerate and other intercalated rocks have a thickness of about 1,500 feet, so that this member as a whole is about 4,500 feet thick. The distribution of this member is widespread, it being found on Dall Island, in the northern part of Prince of Wales Island, on Kosciusko, Hecate, and Tuxekan Islands, southwest of Saginaw Bay, on the east side of Kuiu Island, and on the Kashavarof Islands, Tenakee and Freshwater Bays, Chichagof Island, and Glacier Bay. Possibly to be included with this member is a sequence of green-gray shale with intercalated red beds and thin-layered fine-grained gray sandstone, shale, and dense limestone, somewhat more than 500 feet thick, and occurring west of Edna Bay, on the south side of Kosciusko Island.

The uppermost member of the Silurian sequence in southeastern Alaska consists of green-gray graywacke with sparse conglomerate beds interbedded with red, gray-green, and gray graywackelike sandstones and small amounts of shale. These upper beds are at least 5,000 feet thick and are best exposed in the north half of Prince of Wales Island and on Tuxekan Passage, Naukati Bay, and the east end of Hecate Island. The total thickness of these various members of the Silurian system is thus seen to be about 14,000 feet. The thick limestone and the rocks above it are assigned to an age not older than middle Silurian, and the rocks below the lava member are regarded as early Silurian. This sequence is separated from the next younger formation by a marked unconformity.

The composition of some of these Silurian members raises many interesting speculations that have not yet been solved. For instance, the presence in the coarse conglomerate member of large boulders of granitic rocks is extremely puzzling, because they were evidently derived from a pre-Silurian intrusive mass of that type whose presence has not been recognized in any of the areas hitherto surveyed. Then, too, the association of these very large boulders in beds that were being formed almost in juxtaposition to beds of limestone is almost inexplicable by any of the ordinary processes of sedimentation. Such abnormal relations caused Kirk to suggest the possibility that the conglomerate might indicate Silurian glaciation—a suggestion which has not received general acceptance but which has not yet been proved to be entirely untenable.

YUKON REGION

On the Tatonduk River, north of the Yukon near the international boundary, is a small area of Silurian rocks, and doubtless other representatives of this system occur elsewhere in Alaska in this same district because they have been reported in nearby tracts in Canada. Wherever recognized here the Silurian rocks show little lithologic variation, consisting of massive white to cream-colored limestone. In different places the limestone has been silicified to different degrees, and some of the beds show distinct oolitic phases. The beds have been broadly folded and somewhat broken by faults but have not been intricately deformed. The fossils that have been collected from this limestone have been assigned to the middle Silurian, with the exception of two small collections from the south side of Tatonduk River. One of these collections was identified as coming from a higher horizon than the middle Silurian. There is some doubt as to whether the other collection may not have come from even a younger system, but Mertie regards it as most likely to be Silurian.

In the Porcupine district, to the north, Silurian rocks have been recognized at several localities and show at least two distinct lithologic facies. The lower facies, which is by far the thicker, consists of buff magnesian limestones that are estimated to be at least 2,500 feet thick. Few other kinds of rocks are associated with these limestones, though there are some thin black shaly beds and a little quartzite in the sequence. Overlying this dolomitic member and forming the top of the recognized Silurian section along the Porcupine River is a conspicuous amount of shale which at the extreme top consists of fissile black shale and interbedded dark siliceous limestone. These shales are separated by a marked unconformity from the overlying Devonian rocks. The age of the magnesian limestone, as shown by the fossils it contains, is middle Silurian, about equivalent to that of the Niagaran fauna of the central United States, and the overlying shales are of about the same age or younger, their fauna being comparable with those of either late Niagaran or Cayugan age in the States.

Within the tract lying between the Yukon and Tanana Rivers in central Alaska three principal areas of Silurian rocks have been represented on the geologic map (pl. 1). These are, from north to south, an area in the White Mountains of the Preacher district, a narrow strip in the Tolovana district between the Tatalina and Tolovana Rivers, and a shorter strip near the Tanana River in the southern part of the Tolovana and Hot Springs districts. Although thus interrupted, the three areas form a rather continuous narrow strip nearly 100 miles long, trending roughly northeast. The Silurian system here is represented by a great thickness of calcareous rocks in which both calcitic and dolomitic phases are found. These limestones are commonly massive and somewhat recrystallized, so that their bedding planes are not conspicuous. The rocks are in places closely compressed into pitching folds, and they have been subjected to faulting which here and there has confused their relations to nearby rocks. Accurate measurements of the thickness of the Silurian sequence have not been made, and neither its top nor its bottom has been definitely determined. It appears, however, to be very thick—probably not less than 3,000 feet. Such fossils as have been collected from these limestones have all been assigned to the middle Silurian. This limestone has recently been designated the Tolovana limestone and defined as of middle Silurian age. Although the top of the limestone has not been determined, it apparently is overlain unconformably by the next higher formation, which is believed to be of Middle Devonian age. This is at variance with the belief earlier held that there was an uninterrupted sequence from the Silurian limestones into those of Devonian age, but that belief has long since been found untenable. Beneath the lowest known part of the Silurian section in this area there is apparently a strong unconformity, because these rocks appear to rest on rather highly metamorphosed schists and slates that are here assigned to the undifferentiated Paleozoic or older rocks and that in the area near these contacts are presumably of pre-Ordovician age.

In the eastern part of the Ruby district, where Eakin collected Ordovician fossils, he recognized that there was a great thickness of conformable calcareous rocks that might include representatives of younger beds, and he specifically suggested that some of the limestones there might be as young as Silurian. Mertie, too, in the same general district but farther west, recognized many limestone exposures that probably embraced a great thickness of strata, and he was led to map them as undifferentiated limestones and assign them in general to the pre-Devonian. Brown, in the Nixon Fork area of the McGrath district of the Kuskokwim, which is on the strike of some of these limestones of the Ruby district, reported a similar assemblage of calcareous rocks which in places contained fossils of Ordovician, Silurian, and possibly Devonian age. It is therefore obvious that all these districts contain rocks that are now correlated with the Silurian, but owing to the lack of adequate evidence for differentiating them from others of unlike age, they have perforce been shown on the geologic map (pl. 1) accompanying this report as undifferentiated Paleozoic or older sedimentary rocks. So far as known, these Silurian rocks are everywhere lithologically the same—namely, a great thickness of limestones of both calcitic and dolomitic composition that have been somewhat metamorphosed and markedly deformed and are intricately associated with rocks of other lithologic character and age.

NORTHERN ALASKA AND YUKON REGION

In the northern part of Alaska, embracing both parts of the Sheenjek and Alatna districts of the Yukon region, as well as the Noatak and Kobuk districts of the northern Alaska region, is a broad tract of country which, though not completely surveyed, is evidently traversed by Silurian rocks that are essentially continuous. The general trend of this area is more or less due east, though in different parts the strikes of the individual beds show considerable variety in their directions. This is a notable structural feature of northern Alaska, extending for nearly 600 miles, and is a conspicuous natural object because, throughout most of its extent, its white craggy rocks almost bare of vegetation make striking landscapes. As mapped (pl. 1), this formation consists almost exclusively of massive limestone with only subordinate amounts of rocks of other kinds. In general it is bluish gray, in part grayish and somewhat silicified and in part brownish, weathering to a sugary sand. In some places it is dolomitic, but in others it is a nearly pure calcitic limestone. A few thin beds of nearly black limestone form part of the sequence. This formation was first definitely recognized as Silurian by Schrader, from exposures on the John River in the Wiseman district, and called the Skajit formation, a name that has been perpetuated, though in the revised form Skajit limestone, and is now in general use. The precise relation of this limestone to the underlying rocks has not been settled beyond dispute, but in most places it seems to rest unconformably on highly deformed metamorphic rocks which are probably very much older than the limestone and are regarded as certainly pre-Ordovician, if not pre-Paleozoic.

Throughout most of the extent of the Silurian belt of rocks in northern Alaska the Skajit limestone is the highest member of that system, but in the section of the formation in the Alatna Valley that was examined in some detail, slate, schist, and thin-laminated limestone, lying above the Skajit limestone without noticeable stratigraphic break, were recognized. Even where these higher beds occur there is no evidence that the original top of the Silurian system is present, and in fact it seems practically certain that between the known beds of Silurian and of Devonian age there was a great stratigraphic hiatus, which is represented by the unconformable relation between the two systems. Under these conditions it is evident that no reliable measurement of the thickness of the Skajit, or of the Silurian as a whole, can be given for this district. As a rough approximation, the Skajit limestone may be estimated as probably not less than 6,000 feet thick throughout most of northern Alaska. The thickness of the beds overlying the Skajit limestone is open to even less definite determination, and an estimate of their thickness is likely to be far from the truth. However, to judge by the width of country measured across the strike of these rocks, it seems not unlikely that they may form a sequence not less than 5,000 feet thick.

Only a few collections of fossils have been obtained from the Skajit limestone (pl. 4, *C*). Such as have been determined indicate that the Skajit is not older than middle Silurian, though possibly some of the higher beds from which no fossils have yet been collected may be as young as late Silurian. Lithologic similarity and areal proximity to the Silurian limestones and dolomites on the Porcupine River have in the past led to tentative correlation of the Skajit limestone with these rocks. Such a correlation is entirely in accord with all the facts now known, but it cannot be unhesitatingly accepted as proved because the Silurian limestone on the Porcupine River is definitely placed in the middle Silurian, whereas the Skajit limestone appears to belong very high in that series, if not in the upper Silurian.

Widely scattered throughout other parts of northern Alaska are large masses of limestone whose stratigraphic relations and physical and other characters have not yet been determined with enough detail to warrant assigning them to a more definite position in the stratigraphic column than is occupied by the group of undifferentiated Paleozoic or older rocks. There is little room to doubt, however, that at least some of these limestones will prove to bear a close relation to the Silurian beds described above, if not exactly correlative. Obviously much of that vast unexplored area in the highlands between the Kobuk and Noatak Rivers should have as its bedrock extensive outcrops of the Silurian rocks that were seen near the head of the Alatna and near the mouth of the Noatak.

KUSKOKWIM REGION

Along the northern face of the Alaska Range, extending eastward from a point near the Dillinger River, a tributary of the South Fork of the Kuskokwim, at least as far as the McKinley Fork of the Kantishna River, a tributary of the Tanana River, Brooks recognized a series of argillites in part interbedded with graywacke and associated with chert. In this sequence of rocks limestone is practically absent. To this belt of rocks the name "Tonzona group" was given, and as it was found to overlie rocks of Ordovician age and underlie those of Middle Devonian age, it was assigned to the Silurian or Devonian, though no fossils were found in the group itself. The structure of the rocks of the Tonzona group is highly complex, close folding and even schistosity being common, and the original bedding planes are almost obliterated. No reliable estimate of the thickness of strata included in this group can be made, but evidently it comprises about 5,000 feet of sedimentary beds. Owing to the lack of information as to the precise geologic age to which this group should be assigned, it has been included on plate 1 with other rocks of uncertain age in the undifferentiated Paleozoic or older sedimentary rocks. This is as far as it seems safe to go on the basis of present knowledge, for evidence throughout other parts of Alaska makes it seem improbable that this group embraces rocks that extend from Silurian into Middle Devonian, because, so far as known, no Lower Devonian rocks have been found anywhere in Alaska. It seems most likely, therefore, that this group is either Silurian or Devonian, and not both. As criteria are not available for choosing between these alternatives, the more noncommittal assignment given here has been adopted.

SEWARD PENINSULA

No rocks of Silurian age have been represented on plate 1 in the Seward Peninsula region. This is an omission that was rendered necessary because of the scale of the map, as well as because of lack of information. Beds that are definitely identified as Silurian have been found near Cape Deceit, in the Fairhaven district, and at White Mountain, on the Fish River a short distance south of the town of Council, in the Council district. At the locality south of Council is several hundred feet of a light-gray magnesian limestone much broken by joints and showing very indistinct bedding planes. It contains a few rather poorly preserved fossils, but Kindle [14] considered them identical with certain forms from much richer collections made in the Glacier Bay district of southeastern Alaska and placed in the late Silurian. White Mountain is an isolated knob, cut off from other exposures of bedrock by extensive alluvial filling of the nearby river valleys, so that the surface extent of the Silurian beds is very slight, and their relations to other formations are not closely determinable. On the north coast of Seward Peninsula near Cape Deceit Kindle reported exposures of a highly magnesian limestone, containing fossils that he determined were entirely comparable with the fauna from the magnesian limestone south of Council, and he therefore correlated the two occurrences and assigned them to the later part of the Silurian. Unfortunately, the Silurian outcrops near Cape Deceit are rather isolated from nearby exposures of bedrock, so that their relations to the other rocks of the peninsula are not readily determinable.

That there are other outcrops of thick limestone in Seward Peninsula that may be of the same age as these known Silurian rocks seems almost certain, though they have not yet been recognized as such. Therefore it is regarded as more than likely that parts of the sequence of rocks on Seward Peninsula which are shown on plate 1 as undifferentiated Paleozoic or older sedimentary beds include at least some rocks that are of Silurian age, a conclusion that is in entire accord with the general consensus of opinion of those who have done the most extensive field work in that region.

DEVONIAN SYSTEM

Nowhere throughout the areas that have been surveyed in Alaska have rocks of Lower Devonian age been found. This has led to the belief that one of the great periods of mountain building and diastrophism occurred in the interval between the deposition of the youngest known Silurian rocks in the Territory and that of the oldest of the recognized Devonian formations. Thus, although unidentified by deposits formed during the later part of the Silurian or the early part of the Devonian, this seems to have been an exceedingly important interval in the history of the development of Alaska. Unfortunately the records of that time are necessarily exceedingly fragmentary and difficult

[14] Kindle, E. M., Faunal succession in the Port Clarence limestone, Alaska: Am. Jour. Sci., 4th ser., vol. 32, pp. 347–349, 1911.

to decipher in detail, so that in this report, which treats mainly of the different geologic formations recognized, it is passed over rather summarily, and its real significance may be overlooked by the casual reader.

Deposits formed during Devonian time are widespread throughout many parts of Alaska, and rocks of that age form the bedrock over extensive areas. The Devonian has been recognized in all the major regions except in the south-central part of the Territory, which includes the Copper River, Alaska Gulf, Cook Inlet, southwestern Alaska, and Aleutian regions. Even in those regions there may be unrecognized members of this system which are now grouped with others as undifferentiated Paleozoic or older rocks. The known Devonian rocks include representatives of both the Middle and Upper Devonian epochs, though no attempt at distinguishing between the two has been made in the mapping on plate 1.

SOUTHEASTERN ALASKA

In southeastern Alaska the rocks belonging to the Devonian system are dominantly basic volcanic rocks, graywacke, tuffaceous sedimentary rocks, black slate, conglomerate, and a little chert. They are especially common in the southern part of the region, from Frederick Sound southward, and Buddington has listed the following areas as those where these rocks have been particularly studied, though even there need for much further investigation is strongly indicated: Prince of Wales, Annette, Sukkwan, Suemez, Dall, Baker, Noyes, San Juan Bautista, and Kupreanof Islands, and on Freshwater Bay, Flynn Cove, and Port Frederick, Chichagof Island. Owing to the great variation in lithologic character in relatively short distances, the scarcity of fossils in most of the formations, the complexity of the structure, and the lack of detailed examinations, it has not been possible to fix with certainty the relations between different members of this system in widely separated areas and thus make entirely reliable and close stratigraphic correlations. According to Buddington, the general sequence and character of the Devonian rocks in southeastern Alaska are as follows: Below the lowest recognized Devonian rocks is a strongly marked unconformity which separates them from the pre-Devonian rocks. The oldest of the Devonian rocks are conglomerate, graywacke, and sandstone, with locally interbedded limestone.

This member, which is about 2,000 feet thick, was recognized especially at exposures on San Christoval Channel, at the head of San Alberto Bay, and on the north sides of San Fernando and Lulu Islands—places on the west coast of Prince of Wales Island not far from Craig. Next above are interbedded limestone, slate, chert, andesitic lava, breccia, tuff, and locally conglomerate. These beds were seen on Duncan Canal, at the northwest end of Kupreanof Island, on the north side of Noyes Island, and on Baker Island. Higher in the column are andesitic lava, in part with pillow structure, breccia, tuff conglomerate, and locally rhyolite lava. This member is about 2,000 feet thick and was seen on Prince of Wales, Dall, Sukkwan, Baker, Suemez, and Noyes Islands. This grades upward into about 2,400 feet of gray to green andesitic tuff and graywacke, locally with fine conglomerate, intercalated limestone, and minor amounts of andesitic lava and breccia. Overlying this member is a limestone about 600 feet thick which was noted especially on Long and Round Islands in Kasaan Bay; on San Alberto, Clam, Coronado, and Fish Egg Islands, off the west coast of Prince of Wales Island; and at the north end of Kupreanof Island. All these beds are assigned to the Middle Devonian epoch though the limestone may in its highest part be Upper Devonian. Possibly an unconformity separates the uppermost limestone beds from the next higher beds, which are assigned to the Upper Devonian. These upper beds consist of basalt, andesite, tuff, limestone, sandstone, slate, and conglomerate and were especially well exposed at Freshwater Bay, Chichagof Island; on Suemez and San Juan Bautista Islands; and in the northern part of Kupreanof Island. In the main the determination of the age of these rocks has been based on the marine fossils that they contain or that are found in the rocks with which they are associated, but certain of the determinations are especially interesting because they rest on collections of fossil plants that were obtained from rocks assigned to the Middle and Upper Devonian.

COOK INLET REGION

In the Cook Inlet region no rocks of undoubted Devonian age have been recognized, but in two localities rocks that have been doubtfully assigned to that system have been found. Both of these localities are included with those in which the bedrock is designated as belonging to the group of undifferentiated Paleozoic or older sedimentary rocks. The southern of these localities is in the Iliamna area of the Chinitna district, and the northern is in the Chulitna district. In the Iliamna area Martin recognized several hundred feet of limestone and calcareous schist in the vicinity of Lake Clark and a small exposure of limestone west of Iliamna Bay. These rocks have been much altered by both regional and contact metamorphism, and their relations to nearby strata are so intricate that no definite decision as to their age can be reached. A comparison with known Triassic limestones in the same general region convinced Martin that these must be much older and led him to state:[15] "The Devonian limestones, which

[15] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, p. 35, 1912.

are present in considerable thickness in many parts of Alaska, are perhaps their most probable equivalents."

In the Chulitna district Ross described calcareous sedimentary rocks containing considerable siliceous and argillaceous material and, in the upper part of the section, much chlorite. The beds are usually light gray to nearly white, with a greenish hue, on weathered exposures and dark gray to nearly black in fresher outcrops. All the members have been strongly metamorphosed, and considerable silicification was induced during the metamorphism. The overlying Carboniferous rocks rest on them with a strongly marked angular unconformity. Other than this there is no direct evidence as to their age, and Ross' suggestion that they may be Devonian was necessarily made without any thought that that assignment is more definite than the carefully guarded statement actually expresses. The rocks of this unit have been included on plate 1 in the undifferentiated Paleozoic or older sedimentary rocks.

YUKON REGION

In the area south of the Yukon River between the junction of the Yukon and Tanana Rivers and the international boundary, embracing parts of the Hot Springs, Rampart, Tolovana, Preacher, Circle, Eagle, and Fortymile districts, there are several more or less continuous tracts in which rocks of Devonian age have been recognized. In the lower part of the stratigraphic section these rocks are dominantly clay slate, siliceous slate, chert, and quartzite, with minor amounts or sporadic occurrences of limestone and conglomerate. All the beds are somewhat metamorphosed and are closely folded. In fact, the folding in many places has been strong enough to overturn the folds to the north, resulting in complicated structure and duplication of some of the beds, so that in many places the apparent thickness of this group is much greater than the true thickness. The highest of the Devonian rocks recognized in this area have been designated by the distinctive name "Woodchopper volcanics." This formation, which is most typically developed in the area near the Yukon River between Coal and Thanksgiving Creeks, consists of basaltic lavas of greenstone habit and associated pyroclastic material, interbedded with massive limestone and more or less shale, slate, and chert (pl. 6, *A*). The limestones in this group vary considerably in appearance, the differences apparently depending more on the degrees of metamorphism to which they have been subjected than on original differences in composition. Some of the limestones are dark gray, dense, and noncrystalline; others are partly recrystallized.

Rather few and nondistinctive fossils have been obtained from the lower members of this system, and the age of these members has been determined principally from their stratigraphic relations with adjacent rocks of known age. The age of the sedimentary layers of the higher member has been established with considerable assurance from the fossils that have been collected from them. From all these lines of evidence it is apparent that these rocks are dominantly of Middle Devonian age, though it is by no means proved that some of them may not be as young as Upper Devonian. The total thickness of the beds of the Devonian system, as now recognized in these districts, is in the neighborhood of 10,000 feet, which seems to be about equally divided between the two members differentiated above.

North of the Yukon River, in the Kandik district and extending northward at intervals along the international boundary, are several areas of Devonian rocks. In this district Mertie has recognized Devonian beds at three more or less distinct horizons, at the lowest of which they consist largely of light-gray "lithographic" limestone and dark-gray coarsely crystalline limestone. From general appearance it is often impossible to distinguish between these Devonian limestones and some of the older ones already described. Distinction between the two, however, may sometimes be made by the criterion that the Devonian limestone is much less silicified than some of the older ones. Apparently above the limestone member is an unconformity representing a period of erosion during which some of the limestone may have been removed. Overlying this unconformity are alternating thin beds of dark-gray limestone and shale, with more or less chert at certain horizons. These weaker beds seem to have taken up much of the stresses generated in the later mountain building, for they are much folded but are not recrystallized. The complete thickness of this member has not been determined, but it evidently embraces at least 500 feet of strata in the Tatonduk Valley locality. The highest of the three members of the Devonian sequence in this district is composed essentially of argillite, slate, chert, and cherty grit. The chert seems to be most characteristic of the beds near the top of this member. All the rocks of this upper member have been greatly disturbed during the mountain-building periods and because of their incompetence have been intricately mashed. The thickness of the upper member is estimated as not less than 1,000 feet.

Considerable evidence is available as to the age of these Devonian rocks in the Kandik district from their fossil content. From this evidence and the stratigraphic relations of the rocks, it seems clear that in the main they are of Middle Devonian age. The lowest member is correlated with the Salmontrout limestone, which is described farther on, and is one of the oldest Middle Devonian formations that has been distinguished in the entire Territory. The collections from the uppermost member represent a horizon high in the Middle Devonian, verging close on the Upper Devonian. It may be of interest to note here that in addition to invertebrate fossils the upper member of this Devonian sequence has also yielded plant remains, which were identified by David White.

In the valley of the Porcupine River, near the international boundary, Kindle early measured and described a portion of the Devonian sequence that is exposed there so fully that it has become more or less the type section for the whole east-central part of Alaska. At this place the lowest member of the Devonian exposed is a massive light-gray to blue limestone, weathering to a buff color, that is about 325 feet thick. It rests with apparent unconformity on Silurian graptolite-bearing shales. However, the dip of the rocks of the two systems apears to be concordant, and there is no evidence of marked deformation at the end of the Silurian. Owing to the fact that the limestone is especially prominent near the mouth of the Salmontrout River, a tributary of the Porcupine River, it has been given the distinctive formation name of "Salmontrout limestone." A variety of fossils are common throughout the limestone, and they indicate that, at least at its base, the limestone is of early Middle Devonian age and that the upper parts of this formation are not as young as the Upper Devonian. Overlying the Salmontrout limestone, near the type locality, are brownish shales at least several hundred feet thick. No fossils were found in these shales, but their relations to the limestone are such as to lead Kindle to place them in the upper Devonian. Elsewhere in this same district there is evidence that locally the brownish shales are displaced by basalt flows that are of closely equivalent age to the shales and in places appear to be interlaminated with them, especially toward the top of the section examined.

In the Sheenjek district, in the highlands between the Christian River and the East Fork of the Chandalar, Mertie found a considerable body of rocks which form a stratigraphic unit and which he assigned provisionally to the Devonian. This group consists dominantly of quartzitic sandstones, slaty sandstones, and some argillaceous beds. Many original depositional features, such as bedding and even ripple marks, are well preserved, though the rocks have undergone pronounced deformation by which some secondary features have developed. The structure of the rocks has not been determined with enough precision to warrant a statement as to the thickness of strata included in this member. The fact, however, that the outcrop of these rocks occupies a tract of country nearly 10 miles across the general strike of the formation indicates that it is thick, perhaps including several thousand feet of beds. The age of this group of rocks has not been definitely determined, except by showing that it unconformably overlies the Skajit limestone, of Silurian age, and apparently underlies the early Mississippian rocks to the northeast and that lithologically it resembles rocks to the west whose age has been more definitely determined by fossils as Devonian.

Middle Devonian rocks in the western part of the Chandalar district and the eastern part of the Wiseman district consist dominantly of slate with minor amounts of sandstone and some thin beds of limestone. As these beds are relatively less resistant to weathering and erosion than most of the formations with which they are associated, the topography they produce is characterized by rather subdued forms, even where they form the bedrock of the highlands. This Middle Devonian slate is intricately folded and crumpled, having offered little resistance to the mountain-building forces to which it has been subjected. The northern limit of this belt of rocks has not been surveyed, but from distant views of the Brooks Range, which forms the divide between the Yukon and Arctic Ocean drainage basins, it seems fairly certain that these rocks do not extend much farther north than is represented on plate 1 and almost certainly do not occur in the crest of the range. The determination of the age of these rocks is based on the fossils they contain and their stratigraphic relations. It is significant to note that the fauna of these beds is the same as that from the Salmontrout limestone of the Porcupine district, which, as has already been pointed out, is characteristic of the early part of the Middle Devonian epoch.

Near the junction of the West and North Forks of the Chandalar River and extending westward into the valleys of the Middle and South Forks of the Koyukuk River, nearly to the mouth of Jim Creek, the bedrock is composed mainly of beds that Mertie has correlated with the Upper Devonian or Mississippian series. These rocks are part of the sequence that was originally designated the West Fork "series." They consist of fine dark-gray quartzite, black flint, calcareous black shale, and impure limestone, which are cut by greenish dioritic or basaltic dikes. The structure of these rocks has not been worked out in enough detail to give an insight as to even its major features, and the age of the beds has not been determined closely. Under ordinary conditions it would have been more appropriate to include these beds among the undifferentiated Paleozoic or older rocks on the accompanying map (pl. 1), but such a course would have masked certain facts that the writer feels should be brought out. The representation of this area as of Devonian age on the map seems justified, because the rocks in it are believed to form a more or less definite stratigraphic unit and fossils that are indisputably characteristic of rocks of Upper Devonian age have been collected from the area where these rocks crop out. These rocks unquestionably overlie unconformably the nearby schists and metamorphic rocks, which clearly belong far down in the Paleozoic or pre-Paleozoic sequence, so that to represent the two by the same pattern or symbol would obliterate distinctions that are real and pertinent. Doubtless some of the members of this unit occur north of the area of mapped Devonian nearer the crest of the mountains, but as that region has not yet been explored, this conjecture is not supported by any direct evidence.

In the western part of the Wiseman district and in the Alatna district, farther west, both of which are in the Yukon region, and extending westward into the Noatak Valley and northward across the Brooks Range into the drainage basin of the Killik River, which is a tributary of the Colville River in the northern Alaska region, is a belt from 20 to 25 miles wide that is occupied by rocks correlated with the Devonian system. Much of that belt is still entirely unexplored or at best only cursorily examined, so that knowledge of many of the details regarding the rocks in it must await further surveys. As now known, the Devonian rocks in this area consist of a monotonous assemblage of quartzite, sandstone, and slate, with subordinate amounts of conglomerate and coarse grit and a little limestone. Practically none of these rocks have schistose structure, but all of them have been subjected to stresses that have produced cleavage which, at many places, is more conspicuous than the original bedding. At many other places, however, the original bedding is plainly evident, and even such features as ripple marks and raindrop imprints are preserved.

On the John River rocks that are now correlated with this system were originally mapped as part of the so-called † Fickett series.[16] That "series" as then defined proved later to embrace so many diverse formations that the name was abandoned, and such of the rocks as are now believed to be Devonian are mapped separately from those of other ages. This separation necessarily has had to be based on the rather meager information available from old field notebooks, etc., so that the boundaries as given are more or less diagrammatic and have not been traced out in the field. In spite of the inexactness thus involved, it is believed that, owing to the very small scale of the map, the boundaries as shown depart little from the positions they would occupy if they had been determined in more detail.

In the Alatna, Noatak, and Colville Valleys the distribution and character of the Devonian rocks were studied in somewhat more detail than in the John River Valley, so that the statements regarding the rocks in these valleys are based on later and more complete information, and this has therefore become more or less the type area for much of the northern part of the Yukon region, as well as for the southern part of northern Alaska. Even there, however, the complexity of structure, the enormous areas occupied by these rocks, and the short time that has been given to careful study of them allow only a sketchy treatment of their major characteristics and still leave unaccomplished the detailed determination of the age of different members of the sequence. As stated on page 17, it is not definitely known that the highest Silurian rocks in this area are unconformably below the lowest of the Devonian beds, though this relation is believed to exist, especially as no beds of Lower Devonian age have been recognized here or in any other part of Alaska. How low in the Devonian system are the Devonian beds that occur in this area has not been determined from paleontologic evidence, because most of the fossils that have been collected came from beds that evidently belong toward the top of the exposed section. In fact, practically all the fossils that have been examined seem to belong to an Upper Devonian fauna. The width of the outcrop of these Devonian rocks is so great that even with reasonable allowance for the known complexity of the structure it seems probable that beds many thousand feet in total thickness must be included in this system. Such a thickness strongly suggests that the lower portion of these beds, which lies stratigraphically far below the horizons at which the Upper Devonian fossils were found, may well be of Middle Devonian age. This suggestion seems all the more likely when it is remembered that these rocks appear to be, in part at least, comparable lithologically and in general stratigraphic relation with rocks of known Middle Devonian age in the Chandalar and Wiseman districts, to the east.

Along the northern flanks of the Alaska Range, Brooks noted the occurrence of rocks which he designated the Tonzona group and which he concluded were of Silurian or Devonian age but which are now known to include Carboniferous rocks as well. Owing to the uncertainty as to which system these rocks actually belong in, they have not been represented on plate 1 by the appropriate pattern for any of these systems but have been placed in the group of undifferentiated Paleozoic or older sedimentary rocks. This has been done in spite of the field evidence, which indicates that they are apparently younger than the Ordovician rocks that were seen and apparently underlie unconformably the Middle Devonian rocks. In this same general area and including parts of the Tonzona district of the Kuskokwim region and the Kantishna and Nenana districts of the Yukon region are other rocks that are definitely of Devonian age and are so represented on the geologic map. This formation consists almost entirely of a blue to white limestone, somewhat siliceous, semicrystalline, and usually much fractured. In places a brownish-weathering ferruginous limestone overlies the bluish limestone. The structure of these rocks is complex, and Brooks interpreted the exposures he saw as representing close folding overturned to the northwest or a series of slices caused by a number of more or less parallel thrust faults.

Capps, studying the eastward continuation of this same belt, reported a massive limestone associated with black argillite, slate, and limy argillaceous beds at the headwaters of the Toklat River and in the country on each side of Hanna Glacier. At the locality in the

[16] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey.

Toklat Valley the limestone has been metamorphosed to a marble and shows a variegated coloration ranging from white to pale pink. Near Hanna Glacier the limestone is thoroughly recrystallized and is gray or white on freshly broken faces and shows some silicification on weathered surfaces. At neither of these two localities were fossils found, but from a similar limestone at the head of the Sanctuary River a collection of Middle Devonian fossils was obtained, and fossils of that age were collected by Brooks from some of the limestones in the western part of this belt. On the maps accompanying both the Capps and Brooks reports the larger areas occupied by this limestone have been indicated, but the intimate relations between these rocks and others of less well determined age have made it necessary on the map accompanying the present report (pl. 1) to conventionalize the representation of these limestones and include most of the area along the northern flanks of the Alaska Range west of the Nenana River as dominantly composed of undifferentiated Paleozoic or older sedimentary rocks.

East of the Nenana Canyon, in the valley of Wells Creek, a tributary of the Nenana River, are the easternmost recognized exposures of the thick limestone in this belt of known Devonian rocks near the northern border of the Alaska Range. The limestone here locally forms whole ridges and makes conspicuous natural landmarks. It has been more or less affected by dynamic metamorphism and at places is so altered by silicification as to have lost most of its original characteristics. Associated with the limestone are some conglomerate and slate. All these rocks have been closely folded and usually stand at high angles. In places they have been intruded by granitic igneous rocks, and there the later metamorphism thus effected has been superposed on the earlier metamorphism induced by the mountain-building forces, so that the rocks show especially complex alteration from their original characteristics.

Associated with the limestone, which clearly is of Middle Devonian age, Capps found a thick series of metamorphosed sedimentary rocks which he correlated, at least in part, with the Devonian system, but which for various reasons have not been represented on the map accompanying this report (pl. 1) separately from the undifferentiated Paleozoic or older rocks. These associated sedimentary beds, which are doubtless in part of Devonian age, are described by Capps as including conglomerate, slate, shale, graywacke, quartzite, and thin-bedded and massive limestone. The rocks of this sequence are exposed near a fault of great displacement that angles across the formations in such manner that successively higher beds are exposed at the surface to the north of the fault and toward the west. The lowest beds recognized are a black conglomerate, 200 to 1,000 feet thick, containing pebbles that average about 6 inches in diameter. Immediately overlying this basal member is a hard white conglomerate, 50 to 200 feet thick, whose pebbles are commonly less than 2 inches in diameter and are held in a white or gray siliceous matrix. Above these conglomerates are several thousand feet of slates or argillites and graywacke or quartzite. These beds have a characteristic rusty red color on weathered surfaces. Higher in the section there is a gradual transition from these siliceous and clayey rocks into those of a more limy composition until they pass into the massive gray limestone already noted, which in places is as much as 1,500 feet thick. Still higher are several thousand feet of black slate, chert, and thin-bedded limestone. The structure of the region is so complex that exact relations have not yet been determined, and consequently the true thickness of the group is not known, but apparently the beds that are possibly Devonian may be as much as 10,000 feet in total thickness. No fossils have been found in any of the beds other than the limestone already mentioned, so that the age of the series as a whole is based on general stratigraphic and field relations, and there is no assurance therefore that the group may not include some beds older than the Devonian and some that are younger. With the exception of the larger limestone masses, they have consequently been represented on plate 1 as undifferentiated Paleozoic or older sedimentary rocks.

Still farther east, in the Tok-Chisana district, is a considerable tract occupied by Middle Devonian rocks, though the full sequence of the members of this series has not yet been determined. The most conspicuous member of the Middle Devonian here is a crystalline limestone or group of closely folded limestone beds—at least two and possibly six—that form a most conspicuous line of isolated outcrops, like teeth or pinnacles, standing high above the surrounding softer rocks. The limestone is associated with gray and black slate, hard gray siliceous beds, yellowish sandy and gritty beds, and brown micaceous schist, probably resulting from intrusion by a large body of diorite. These rocks occupy a long wedge-shaped area opening out to the southeast, but little is known of their structure, thickness, and relation to other formations, except that they abut against the Carboniferous rocks and structurally are overlain by Mesozoic sediments on the southwest. The limestone is fossiliferous. None of the beds are over 200 feet thick.

In the extreme eastern part of the Alaska Range, in the Chisana district near the international boundary, Capps reported finding a small area of Devonian rocks on Bonanza Creek. The area occupied by these rocks, however, was so small that it could not be represented to scale on the reconnaissance map accompanying his report and obviously cannot be indicated on the accompanying map (pl. 1). According to Capps, the Devonian rocks that have been identified in the Chisana district consist of basic lavas, agglomerates, and tuffs associated with considerable black shale and minor amounts of graywacke. These beds, in addition to their monoclinal tilting, have been greatly folded and are cut by some faults. The fossils contained in these beds were identified as belonging to a Middle Devonian horizon that seemed comparable to that of the rocks at Freshwater Bay, in the Chichagof district of southeastern Alaska. Only very approximate estimates as to the probable thickness of the beds correlated with these Devonian rocks in the Chisana district can be given, but apparently at least 1,500 feet of strata belong to this unit.

KUSKOKWIM REGION

Part of the recognized Devonian sequence in the Kuskokwim region has already been referred to in describing the Devonian rocks that have been found along the northern flanks of the Alaska Range from the Tonzona district of the Kuskokwim region eastward to the Nenana district of the Yukon region. Another considerable area of recognized Devonian rocks occurs in the Kuskokwim region near the settlement of McGrath. The Devonian rocks of this district were recognized by Spurr in the course of his explorations in 1898, and he named them the † Tachatna series (now Takotna), for the stream near whose junction with the Kuskokwim these rocks are especially well displayed. At this place the rocks are gray, generally thin-bedded limestone associated with calcareous, carbonaceous, and chloritic shales and some fine-grained arkose. All these rocks have been considerably folded, and in places they are cut by granitic dikes. At places the limestone is said to be highly fossiliferous, the fossils for the most part being corals. No close determination of the age of the fossils collected has been made, though Charles Schuchert, who gave tentative identifications of the forms, was inclined to regard them as Middle Devonian.

It has elsewhere been noted that in the Nixon Fork area of the McGrath district Brown recognized a number of exposures of great limestone beds, some of which contained Ordovician fossils and others Silurian fossils. It now becomes appropriate to call attention to the fact that some of these limestones also contain a Devonian fauna. Inasmuch, however, as the field work was done on only reconnaissance standards, it was not possible to map these different systems separately, and these Devonian limestones, as well as those of the earlier periods, have been grouped together on plate 1 as undifferentiated Paleozoic or older sedimentary rocks.

Thick-bedded limestones that may be of Devonian age are known in other parts of the Kuskokwim region, though there is as yet no definite evidence available that would warrant their specific assignment to that system. For instance, in the Lime Hills, which are in the extreme southern part of the Georgetown district, there is a series of Paleozoic limestone hills extending in a northeasterly direction for many miles in the area between the Hoholitna and Stony Rivers. Little is known that would lead to a specific assignment of this limestone to any definite system, but it is significant that the formation next overlying this limestone contains pebbles derived from some of the underlying rocks, and these pebbles contained fossils that were identified as from either an Upper Devonian fauna or a Middle Devonian fauna closely equivalent to that of the well-determined Salmontrout limestone of the Porcupine River district, in the eastern part of the Yukon region. These fossils thus demonstrate that Devonian rocks occur in that general region, even if they have not yet been recognized or even if they are not exposed at the surface there at the present time.

SEWARD PENINSULA

No rocks of Devonian age have been specifically indicated on the map (pl. 1) as occurring in Seward Peninsula. This absence should not be taken as proof that Devonian rocks do not occur there; rather it indicates that the present state of knowledge does not permit their being mapped as such. As a matter of fact, at several places in the peninsula fossils that have been assigned to the Devonian or younger Paleozoic systems have been collected. The two places in Seward Peninsula where there seems to be best evidence of Devonian beds are at Black Mountain, in the Council district, near the south-central coast, and at Baldy Mountain, in the Kougarok district, in the central part of the peninsula. At the Black Mountain locality, which is some 5 miles north of the Silurian locality at White Mountain, there is a small isolated exposure of nearly black thin-bedded limestone with rather abundant fossils. At the Baldy Mountain locality the limestone is bluish gray and considerably more recrystallized than that at Black Mountain. The fossils collected from both these localities were orginally identified as probably representing a Silurian fauna. Kindle,[17] however, on the basis of further field work, during which additional collections were made, concluded that these limestones probably represented a single horizon and were either Devonian or Carboniferous, and he was more inclined to favor the later rather than the earlier system.

Poorly preserved fossils that are somewhat suggestive of a Devonian fauna have also been obtained from other limestone areas in Seward Peninsula, but the evidence they afford is so inconclusive that it cannot be taken as indicating more than that widely distributed in Seward Peninsula are extensive areas of limestone, now mapped as included within the undifferentiated Paleozoic or older sedimentary rocks, that merit further study, if all the occurrences of Devonian rocks are to be properly discriminated. Such a study should not nec-

[17] Kindle, E. M., Faunal succession in the Port Clarence limestone, Alaska: Am. Jour. Sci., 4th ser., vol. 32, pp. 348–349, 1911.

essarily be limited to the areas in which limestone forms the bedrock, because in parts of the peninsula arenaceous and argillaceous rocks, both largely and little metamorphosed, seem to be stratigraphically so placed as to appear certainly younger than rocks of Ordovician age and possibly younger than rocks of Silurian age. That this is no new concept is shown by a report by Moffit[18] published in 1905, in which he definitely indicated the probability that some of the schists of northeastern Seward Peninsula overlie the limestones of the western part of the area and even those of Baldy Mountain that are now considered probably Devonian or younger. Collier[19] suggested a Devonian or Silurian age for the upper part of the Nome group and gave as criteria for that distinction the facts that they overlie the Silurian (now considered Ordovician) limestone and contain less chlorite than the older members of the Nome group.

NORTHERN ALASKA

The Devonian in the belt of rocks that extends westward from the Alatna and Wiseman districts of the Yukon region into the Colville and Noatak districts of northern Alaska has been discussed in preceding pages. The only other place in northern Alaska where Devonian rocks have been definitely indicated on the map is in the Lisburne district, though possibly rocks of this age may be present but not yet definitely recognized in the western part of the Noatak Valley and in the Canning River district.

In the Lisburne district Collier described a heavy calcareous sandstone and interbedded calcareous slates forming sea cliffs for nearly 15 miles along the coast north of Marryat Inlet and outcrops along the western part of the Kukpuk River. Some of the members are said to show schistosity, but the rocks as a whole are not strongly deformed, as their structure is said to consist of a series of broad open folds whose dips rarely exceed 30°. The total thickness of these beds is not less than 1,000 feet and is probably very much greater. As no fossils have been found in these rocks their age has been assigned on stratigraphic evidence, based principally on their relation to known Carboniferous rocks. Collier, on that evidence, states that these sandstones are certainly older than Carboniferous and therefore assigned them tentatively to the Devonian. Subsequent studies in nearby areas indicate that the general structure of the Paleozoic and related rocks in the Lisburne district is very much more complex than was originally recognized, so that considerable doubt is felt as to whether the evidence on which Collier relied is really of much significance. This doubt, however, is not founded on any direct specific evidence opposed to Collier's interpretation, and it would be entirely unwarranted at this time to alter the age assignment heretofore given for these rocks. The most that seems justified now is to accept these rocks as Devonian, but note that much more detailed work will be required to prove beyond doubt the correctness of that assignment.

In the Canning River district Leffingwell recognized a unit consisting of more than 1,000 feet of black shale, slate, and possibly minor amounts of sandstone. These rocks apparently overlie highly metamorphic schists and underlie conformably the Mississippian limestone. They have a fairly widespread distribution, being well exposed in the Canning and Hulahula River Valleys. The shale is folded with the other nearby Paleozoic rocks, but owing to its greater weakness has been much more deformed than the resistant rocks. No fossils were found in this formation, so that determination of its age had to be based on such evidence as was afforded by the stratigraphy. On this ground the shale was correlated with either the lower members of the Carboniferous or the upper part of the Devonian sequence. Such restricted range seems rather closer than the field evidence would entirely warrant, and it has therefore, seemed advisable not to differentiate this unit on the map from the undifferentiated Paleozoic or older sedimentary rocks.

In the southwestern part of the Noatak Valley rocks of Silurian and Carboniferous age are shown on plate 1, but a considerable tract of unexplored country north of the Agashashok River, a tributary from the east, has been left uncolored. It seems highly probable that rocks of Devonian age form a more or less continuous strip through the unexplored country between the Kobuk and Noatak Rivers and connect with the Devonian rocks that have been mapped in the headward portion of the Noatak Valley east of the Aniuk River. However, in the absence of any evidence to support this belief the entire unexplored area has necessarily been left blank.

CARBONIFEROUS SYSTEM

Geologists in the main recognize that the great Carboniferous period, which is estimated to have been some 100,000,000 years or more ago, is divisible into three principal epochs, which, from youngest to oldest, are called the Permian, the Pennsylvanian, and the Mississippian. Each of these epochs apparently spanned about equal lengths of time that may have roughly approximated 2,000,000 years. Nowhere on the earth is there an area in which a continuous stratigraphic column of all the rocks that were formed during this period acn be examined, so that this sequence has been evolved by piecing together bits of sections from many different lands. In Alaska, so far as now known, the earliest unit, the Mississippian, is widely distributed and has been recognized and mapped in practically every major geographic region with the exception of

[18] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 247, p. 24, 1905.

[19] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougarok, Port Clarence, and Goodhope districts: U. S. Geol. Survey Bull. 328, p. 65, 1908.

southwestern Alaska. Formerly certain Alaska rocks were identified as belonging to the Pennsylvanian series, but many of these on more detailed examination have proved to be older than Pennsylvanian and have therefore been placed in the Mississippian, so that at present only a few doubtfully determined formations are regarded as possibly part of the Pennsylvanian series. Rocks of the uppermost series, the Permian, are by no means uncommon in Alaska, though not as widespread nor representing so great a thickness of beds as those of Mississippian age.

In the following descriptions it has not proved feasible to trace sequentially each one of the three series throughout the Territory before passing to the descriptions of the next younger series, and instead the plan has been adopted of describing completely all the known members of the Carboniferous system in one district before passing to the next district. Although this plan may result in obscuring some of the larger relations of the major divisions, it should make plainer the stratigraphy within the smaller subdivisions, in which close correlations can be made more accurately.

SOUTHEASTERN ALASKA

Although rocks of Carboniferous age have been definitely recognized at widely separated areas in southeastern Alaska and probably also occur there at many places where their identification has not yet been made with sufficient certainty to permit their being definitely represented as Carboniferous on the geologic map, their outcrops do not cover very extensive tracts. So far as known the best sections of these rocks are on Kuiu and Admiralty Islands, about in the central part of the southeastern Alaska region, but good exposures of parts of the sequence are known in the Wales district, especially near Klawak; in the Keku Islands of the Kupreanof district; and in the Iyoukeen Peninsula of the Chichagof district. There is a strong probability that certain of the more or less highly metamorphosed rocks of the Ketchikan and Wrangell districts, here mapped as undifferentiated Paleozoic or older, may belong to the Carboniferous system. These rocks have been almost completely changed by processes attendant on the injection of the great granitic masses by which they are intruded. In spite of these changes many of the limestone beds there still preserve numerous signs of crinoid columns, which, though not of determinative value as to the age of the rocks in which they are found, still strongly suggest that they represent a Carboniferous fauna.

The lowermost of the recognized Mississippian rocks in southeastern Alaska appear to be thin conglomerate beds and calcareous arkose exposed in the west-central part of the Wales district, in the general vicinity of Klawak. These beds there and elsewhere are succeeded by highly fossiliferous crystalline limestone and black thin-layered chert, which, in turn, are overlain by interbedded dense gray quartzite and cherty limestone with sparse sandstone, conglomerate, and limestone. In general, the contact of these beds with those of the older systems are covered or obscured by faulting, so that its exact character is not determinable, but there is no apparent angular unconformity between the Mississippian rocks and those recognized as belonging to the upper part of the Devonian system. The fossil faunas, obtained mainly from the massive limestone of this sequence, show considerable local variation between collections from different areas, so that even now certain of these faunas are recognized as displaying aspects that suggest Pennsylvanian affinities. Girty, however, who has made the most comprehensive studies of these collections, as well as of those from other Carboniferous localities in Alaska and the States, has concluded that they may best be referred to the upper Mississippian and correspond closely with the Lisburne horizon, noted further on.

Overlying these Mississippian rocks, with apparently no stratigraphic break, is a massive white limestone, which has been found at only one locality in the whole region. This locality is an island in Soda Bay, on the west coast of Prince of Wales Island. The limestone is at least 100 feet thick and apparently lies in the trough of a syncline, with rocks of Mississippian age on each side. The fossils collected from it are not such as to be truly diagnostic, but they so strongly suggest Pennsylvanian age that Girty has provisionally assigned them to that epoch. More detailed examination of the locality will be required before this determination can be regarded as definite, but should it be confirmed by that study it would be of special importance, because it would prove the presence of Pennsylvanian rocks, which are unknown not only elsewhere in southeastern Alaska but in any other part of the Territory.

Forming the highest members of the Carboniferous sequence in southeastern Alaska are rocks that are now assigned to the Permian epoch. At the bottom of the section of this series are a variety of rocks, including thick conglomerate, black calcareous shales with layers of brown-weathering limestone or buff calcareous sandstone, basaltic and andesitic lava that in part has a pillow structure, andesitic tuff and white chert, brownish-weathering thick-bedded medium-grained white limestone, sandstones, and rarely felsite breccias, tuffs, and flows.

The most complete sections of these lower members of the Permian series are exposed on Kuiu Island and the Keku Islands, in the Kupreanof district. Above the lower members is a white limestone with intercalated layers of white chert. This upper member of the Permian series is perhaps best known on the north end of Kupreanof Island, at Hamilton Bay and near Kake; on the Keku Islands; on Kuiu Island; at Pybus and

Herring Bays, Admiralty Island; and on the mainland at Taku Harbor and at the entrance of Holkham Bay, in the Juneau district. In general, the fossils contained in these rocks represent a fauna unlike that characteristic of the Permian beds in the States and more like that from Russian localities. The great distance that separates these two areas, however, makes precise correlation between them impossible at present, and therefore the specific determination of the age of the rocks from which the fossils were collected is doubtful. In fact, it seems not unlikely that, with more complete knowledge of the fossil faunas of the Carboniferous of Alaska, some of the now accepted correlations may require revision.

The relation of the youngest Carboniferous rocks to the next overlying formation is such as to suggest everywhere in southeastern Alaska a marked stratigraphic break, though that break apparently was not induced by strong deformation.

COPPER RIVER REGION

The oldest sedimentary rocks in the Copper River region to which definite age assignments have been given are representatives of the Carboniferous system. Both the lower subdivision, the Mississippian, and the uppermost subdivision, the Permian, are represented in different parts of the region, but no rocks of Pennsylvanian age are now recognized there.

In general the Carboniferous rocks form two more or less distinct areas, trending west-northwest, in the Copper River region. The southern area extends westward mainly along the south side of the Chitina Valley from the Tana River, crosses the Copper River, and thence extends to and beyond Klutina Lake, until it disappears under later rocks near Tazlina Lakes. The northern area embraces the eastern part of the Wrangell Mountains near the international boundary and thence, sweeping west-northwestward, forms a more or less continuous outcrop along the southern flanks of the Nutzotin Mountains and the southern ridges of the Alaska Range, as far west as the pass by which the Richardson Highway crosses the divide, to the drainage basin of the Tanana Valley north of Paxson. The oldest rocks of this system comprise slate and schist locally associated with a minor amount of altered limestone, tuffaceous beds, and basalt flows. They include, among others, the Strelna formation and possibly part of the Klutina group. Younger than this lower assemblage of rocks is a great thickness of lava flows, tuffs, and volcanic breccia, interstratified with shale, limestone, limy shale, sandstone, and conglomerate. Conformably overlying these intermediate beds is a great thickness of basaltic lava flows that have long been known by the specific name "Nikolai greenstone." The lower of these three units is correlated with the Mississippian. The intermediate unit was originally assigned to the Pennsylvanian, but that correlation was later set aside, and the unit is now included in the Permian sequence. The uppermost unit is now generally held to be Permian, though part of it may be somewhat younger.

All these Carboniferous rocks are considerably folded and faulted—in fact, some of the older ones of Mississippian age have been subjected to such strong mountain-building forces that they have been altered into schists through dynamic metamorphism. The Permian rocks, although much folded and faulted, are not schistose, though in places rather thoroughly recrystallized. The deformation of the Carboniferous rocks took place before the deposition of the overlying shales of the Triassic system, as these shales lie unconformably on the upturned and eroded layers of the Carboniferous limestone. The Mississippian series is estimated to have a thickness of not less than 6,500 feet. The basal and middle parts of the Permian series are estimated to be several thousand feet thick, and the upper part, the Nikolai greenstone with the associated lava flows, has a thickness of 5,000 to 6,000 feet. Thus the entire Carboniferous section is probably considerably more than 10,000 feet thick.

COOK INLET-SUSITNA REGION

Although Carboniferous rocks may be present in the areas now mapped as undifferentiated Paleozoic or older sedimentary rocks in the Cook Inlet-Susitna region, the only place where they have been definitely identified and mapped as Carboniferous is in the Chulitna district. In this district Ross has mapped a varied assemblage of rocks of this age, in which tuff, volcanic breccia, and lava predominate but at places argillite, limestone, chert, and conglomerate are common. The sequence is much deformed and in places badly broken by faults. Five distinct subdivisions of this sequence, based on lithologic and stratigraphic differences, have been made, and the sequence evidently includes beds several thousand feet thick.

The fossils collected from the limestone in the lower part of the section were thought by Girty to be probably Permian, though he felt that it was safer to refer them less definitely to the Carboniferous system. These beds appear to grade imperceptibly upward, without break, into beds that carry Triassic fossils, so that there is here no marked angular unconformity between the two systems. The difference in faunas, however, shows that there must be a pronounced disparity of time between the two and consequently a break that has not yet been recognized in the section.

YUKON REGION

The known Carboniferous rocks in the Yukon region are more or less localized in its eastern and northern parts, though there is some evidence that members of that system which have not yet been recognized as such may be much more widespread. The recognized Carboniferous rocks have been appropriately indicated on the geologic map (pl. 1), but those other areas that may contain representatives of this system have been included in the undifferentiated Paleozoic or older sedimentary rocks.

In the extreme southeastern part of the Yukon region, near the international boundary, the northern area of Carboniferous rocks of the Copper River region already described extends northward to form the bedrock of part of the White River Valley, which is tributary to the Yukon, and of the Nabesna and Chisana Rivers, which are tributaries of the Tanana River, itself a tributary of the Yukon, and rocks in this same belt occur at intervals toward the west in the mountains that form the divide between these two great river systems. Near the junction of the Chisana and Tanana Rivers a separate exposure of rocks, now correlated with the Carboniferous system, has been found. The rocks at this locality originally, as reported by Brooks, were said to consist, at the base of the section, of coarse massive conglomerate, interbedded with some beds of clay slate, and in the upper part almost entirely of slate. The top of the sequence was not seen, but the section was believed to embrace some 1,000 to 2,000 feet of beds. The name "Wellesley" was given to this unit, but separate recognition of these beds was discontinued, and they have been included as part of the Mississippian and probably belong well toward the base of that series.

In the great triangular tract lying between the Yukon and Tanana Rivers and including a small strip of country immediately adjacent to the northern bank of the Yukon are numerous places where Carboniferous rocks occur. What has been learned about these various occurrences has recently been reviewed by J. B. Mertie, Jr., and from his summary of conclusions the following abstract has been made. In this area the Carboniferous may be divided into seven more or less distinct units, which, arranged as far as practicable from oldest to youngest, are as follows: Livengood chert, an unnamed assemblage of undifferentiated beds, limestone beds, Rampart group, Calico Bluff formation, Nation River formation, and Tahkandit limestone. The respective ages of these different units are not yet determined with sufficient certainty, so that the order given is not to be regarded as established with finality.

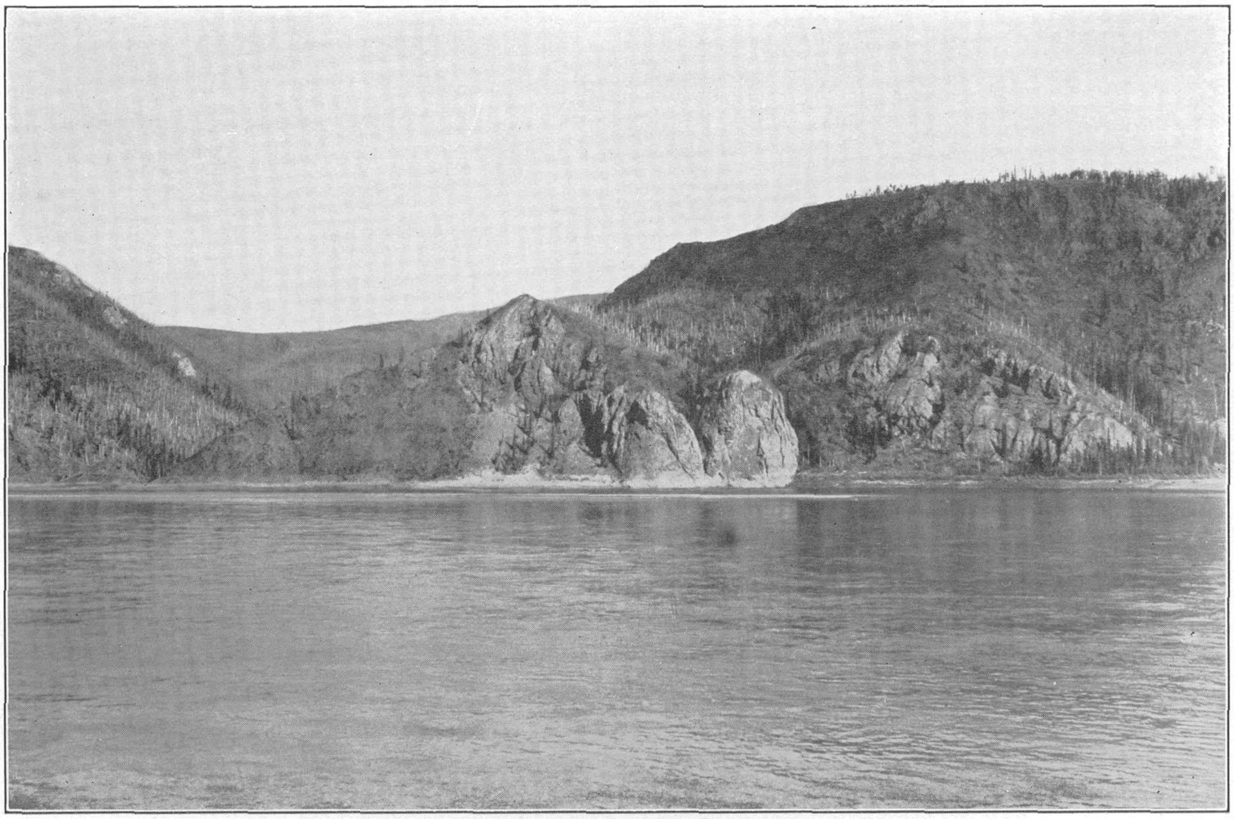
The Livengood chert is known to extend from the Sawtooth Mountains to the White Mountains, a distance of about 65 miles, and an eastern extension in the valleys of Beaver and Preacher Creeks prolongs the belt another 30 miles. As the name suggests, the formation is composed dominantly of chert, with minor amounts of interbedded limestone and argillaceous rocks. The chert is considered by Mertie to be of primary origin, though this conclusion is not yet regarded as proved. The rocks of this formation are strongly folded and have experienced the general regional deformation whereby they are part of a major folded structure that has been overturned from the south to the north. Probably the Livengood chert embraces a total thickness of several thousand feet of beds, which are assigned to the Mississippian series.

Mertie's unnamed assemblage of undifferentiated Carboniferous rocks necessarily includes rocks of widely dissimilar composition and age, but a part of it immediately overlies the Livengood chert and is below the next higher subdivision. Lithologically, the rocks consist of schist, shale, slate, chert, sandstone, quartzite, and limestone. The limestone becomes more abundant in the upper part of the section, until in the next higher unit, called by Mertie the limestone beds, it becomes the predominant rock type.

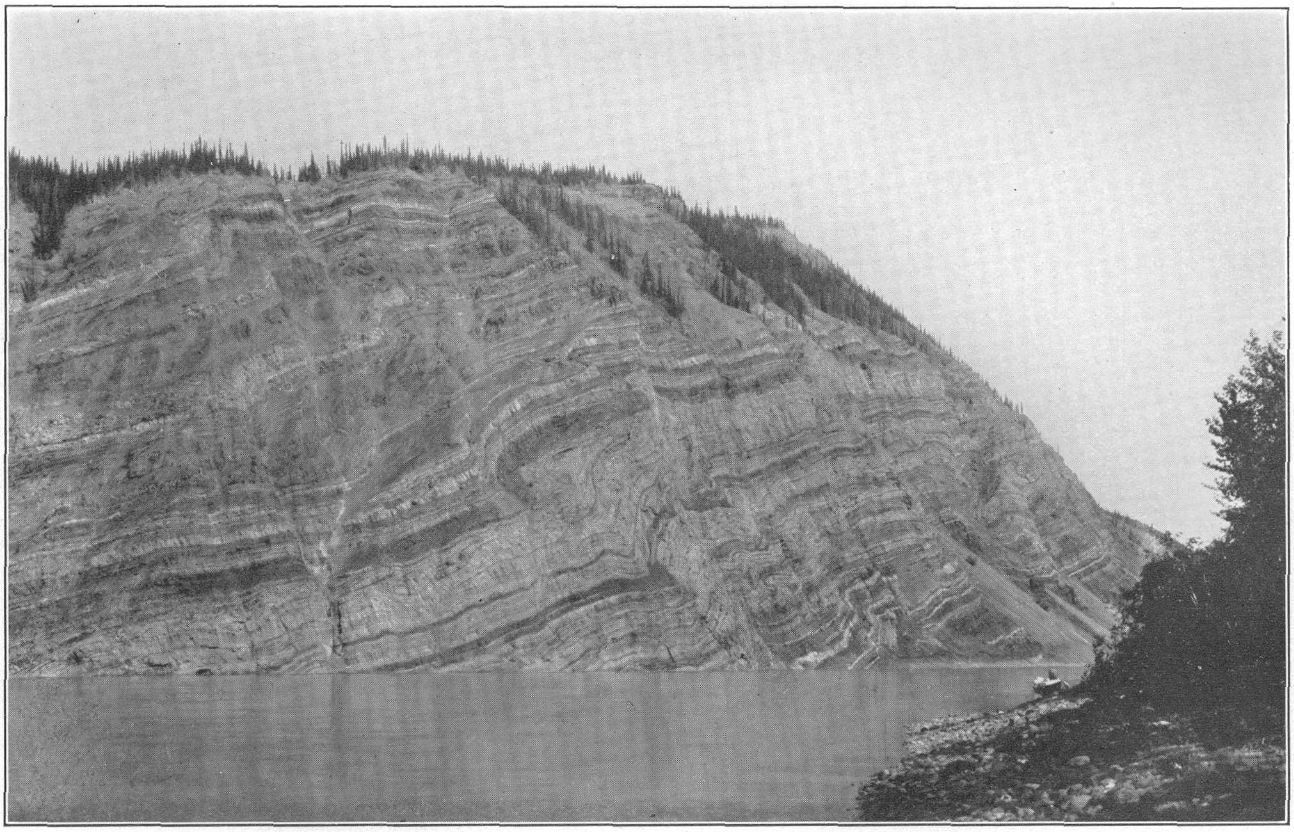
The Rampart group is an assemblage of sedimentary rocks and interbedded lava flows, especially well displayed in the Rampart district but correlated with rocks extending into the Tozi and Melozi districts, to the southwest, and the Dall district, to the north. Correlated with the Rampart group, but farther east, are volcanic rocks that have been called the Circle volcanics. In the type locality the rocks of the Rampart group are strongly folded and locally faulted and brecciated. The total thickness of the formations of this group has not been determined, but it possibly is as much as 5,000 to 10,000 feet. Fossils from the sedimentary members of the group clearly indicate a Mississippian fauna, but the precise position of the group with respect to the other members of the Mississippian sequence is by no means definitely determined, though the present indications point to the suggestion that it is older than the Calico Bluff formation and younger than the Livengood chert.

Overlying the limestone beds is the Calico Bluff formation (pl. 6, *B*). At the type locality, in the Eagle district, this formation consists of alternating beds of limestone and shale with some slate. This thickness of the formation as determined by Mertie is 1,270 feet. The rocks have been only gently folded and are abundantly fossiliferous. Nearly 120 genera of animals, representing perhaps more than 250 species, have been identified from the fossils collected from this formation, and they clearly indicate an upper Mississippian fauna that is roughly comparable with that of the Chester group in the States.

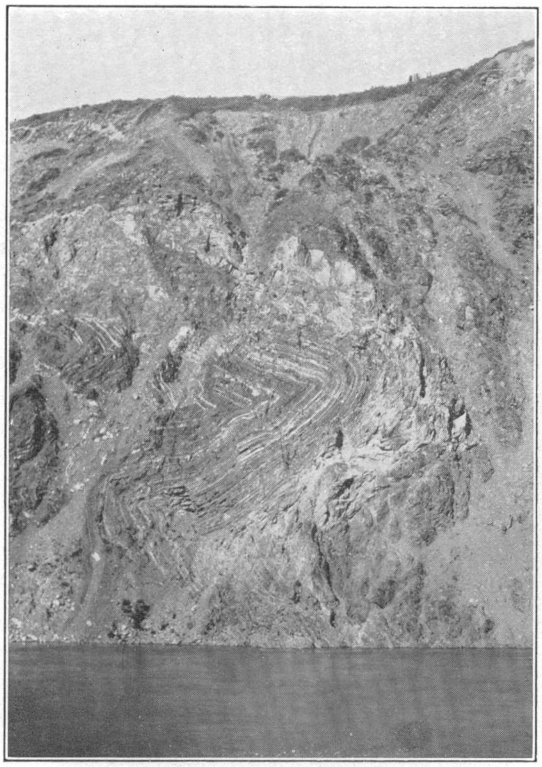
The Nation River formation is exposed typically in the vicinity of the Nation River and in adjacent parts of the Yukon Valley. It consists of a thick sequence of continental deposits comprising well-indurated clay shale, sandstone, and conglomerate. A bed of bituminous coal occurs in the section about three-quarters of a mile from the junction of the Nation River and the Yukon. The beds in places are closely folded and are cut by faults of undetermined displacement. The esti-



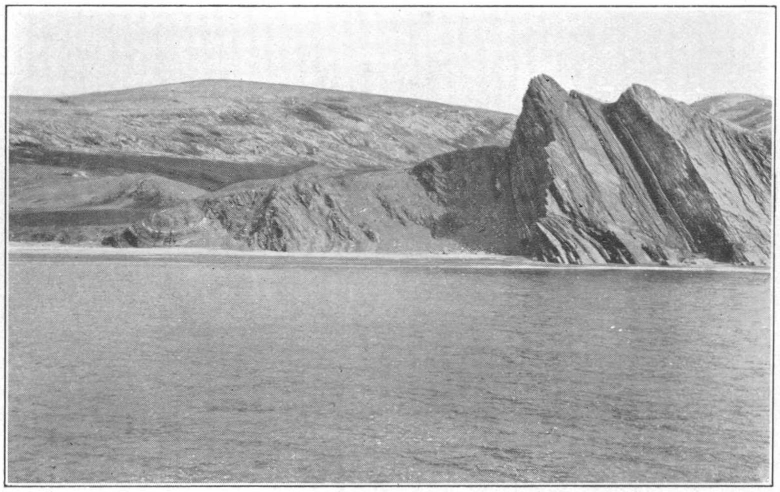
A. TWO BEDS OF FOSSILIFEROUS LIMESTONE ASSOCIATED WITH THE WOODCHOPPER VOLCANICS, ALL OF MIDDLE DEVONIAN AGE.
On north bank of Yukon River opposite mouth of Woodchopper Creek.



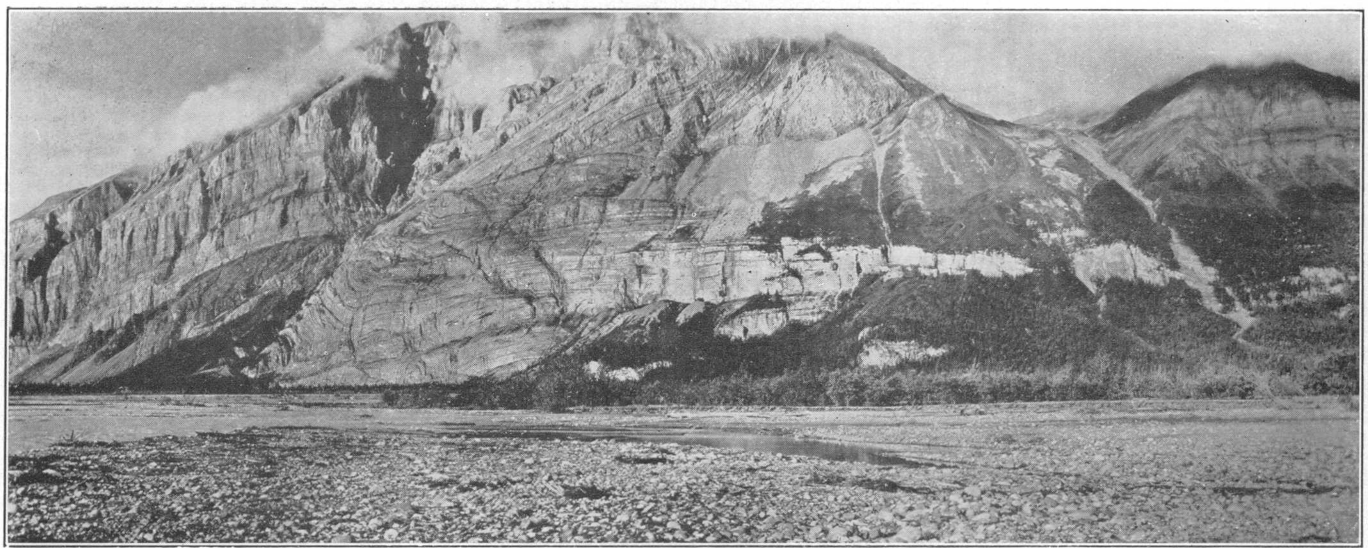
B. OUTCROP OF CALICO BLUFF FORMATION, OF MISSISSIPPIAN AGE, IN BLUFFS OF YUKON RIVER A SHORT DISTANCE DOWNSTREAM FROM EAGLE.



A. DEFORMED SHALES AND ASSOCIATED ROCKS OF NOATAK FORMATION, OF MISSISSIPPIAN AGE, EXPOSED IN CANYON WALLS OF NOATAK RIVER.



B. LISBURNE LIMESTONE AND ASSOCIATED ROCKS OF MISSISSIPPIAN AGE EXPOSED IN THE HILLS AND CLIFFS A SHORT DISTANCE SOUTH OF CAPE LISBURNE.



C. GREAT FAULT WHICH DISLOCATES CHITISTONE LIMESTONE, OF TRIASSIC AGE, AND THE NIKOLAI GREENSTONE, OF PERMIAN AND IN PART, POSSIBLY, OF TRIASSIC AGE, IN THE VALLEY OF NIZINA RIVER mated thickness of the formation ranges from 3,700 to 6,000 feet. The only fossils that have been collected from the formation are plant remains, and the identifications that have been made suggest that they are Mississippian or Devonian. The stratigraphic relations of this formation to the other rocks of the region, as well as to the general sequence of events in the Carboniferous throughout the Territory, make this paleobotanic determination stratigraphically unacceptable, and in spite of the possibility that the formation is Mississippian, Mertie has felt that it is more likely to be Pennsylvanian, though leaving open final decision as to the age.

The uppermost formation of the Carboniferous system is the Tahkandit limestone, the type locality for which is near the Yukon River a short distance east of the mouth of the Nation River, a stream whose Indian name was "Tahkandit." In the main this formation consists of limestone, but in its lower part are beds of conglomerate, sandstone, and shale. A section measured by Mertie at the type locality showed a thickness of 527 feet, of which 373 feet is limestone, though the top of the section was not recognized and some uncertainty as to its completeness is caused by local faulting. The formation is abundantly fossiliferous, nearly 60 genera and 140 species having been identified. Originally, with less extensive collections available for study, the formation was regarded as Pennsylvanian, but in the light of fuller information it is now identified as Permian and assigned to the lower part of that series.

In the Porcupine district, according to Kindle and Brooks, the Devonian rocks are not separated from the Carboniferous by any physical break, but the two systems grade imperceptibly into each other. Rocks that closely resemble the Calico Bluff formation on the Yukon were recognized and described as consisting of interbedded dark-colored shale and limestone. Other collections from the upper ramparts of the Porcupine have been identified by Girty as Permian. Only hasty exploratory work was done in the Porcupine region, so that information as to any but the most general features of the occurrence of these rocks is lacking. Farther north along the international boundary, between the Porcupine River and the coast of the Arctic Ocean, Maddren [20] found two areas of Carboniferous rocks, one about 60 miles north of the Porcupine River and west of the Old Crow River, and the other, still farther north, extending for a width of about 40 miles along the boundary between Ammerman and Tub Mountains, including much of the valley of the Firth River. In general in both these areas the Carboniferous rocks are bluish-gray crystalline limestone with smaller amounts of arenaceous and argillaceous rocks. Folds are common, and in places the folding has been so intense that the beds are overturned. Fossils are abundant in many of the beds and fully justify the assignment of these rocks to the Carboniferous system, and at least part of them to the Mississippian series.

In the Sheenjek district and in the eastern part of the Chandalar district Mertie distinguished three units, the youngest two of which are unquestionably Carboniferous, and the oldest belongs either in that system or high in the Devonian system. The oldest of these units consists principally of chert and slate, with associated basic intrusives. It is exposed most extensively along the Sheenjek River Valley from Lookout Point to Monument Creek and in a smaller area in the mountains in which the Koness River heads, south and west of the junction of Old Woman Creek and the Sheenjek River. In view of the uncertainties as to the system to which this unit should be assigned its distribution has been shown on plate 1 by the pattern for the undifferentiated Paleozoic or older sedimentary rocks. Overlying this unit and apparently conformable with it is a unit consisting mainly of quartzite, conglomerate, and slate. This unit is most extensively exposed in the headwater region of the Sheenjek Valley north of Table and Brushman Mountains. The component grains and pebbles in the rocks of this unit are predominantly chert and vein quartz, in a highly siliceous matrix that in many places is cherty. Physically this unit has many resemblances to the Livengood chert of the Yukon-Tanana region, but it differs from that formation in containing much vein quartz and in overlying rather than underlying a chert formation. Specific determination of the age of this unit must await more detailed studies, but all the available evidence points to these rocks being Carboniferous, and their relation to known Mississippian rocks indicates a position near the base of that series.

The youngest unit of the Carboniferous sequence in the Sheenjek and eastern Chandalar districts is a thick limestone. At a distance the limestone appears to be well bedded, but on closer examination the apparent stratification is seen to be caused by innumerable stringers and bands of chert and lines of silicification. The limestone is usually dark gray to black on fresh fracture but weathers to a light gray blue. Apparently the formation is not closely appressed, but strong dips are common. Although no precise measurements of the limestone have been made, its apparent thickness is judged to be approximately 6,000 feet. No determinative fossils have been obtained from the limestone of this area, but such as have been found suggest a position rather low in the Mississippian sequence, probably not as high as that occupied by the Calico Bluff formation. On the other hand, a comparison with other areas in which this limestone is exposed and in which more diagnostic fossils have been found suggests that the limestone really represents beds near the top of the Mississippian and is to be correlated with the Lisburne limestone, of late Mississippian age.

[20] Maddren, A. G., Geologic investigations along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 310–312, 1912.

In the unexplored area in the central and northern part of the Chandalar district, as well as still farther west in the northern part of the Wiseman district of the Yukon region and in the adjacent headwaters of the Colville and Noatak districts of northern Alaska, there are large stretches of country in which Carboniferous strata form the bedrock. In the part of this tract lying within the Yukon region, however, the only place where these rocks have been definitely indicated on the map is in the headward portion of the John River Valley. As this forms so small a part of the section of these rocks, which are much better known in the adjacent parts of northern Alaska, it has seemed best to omit partial description of the John River localities here and instead treat them with the northern Alaska occurrences.

NORTHERN ALASKA

In northern Alaska Carboniferous rocks have been studied and identified in three principal areas, though had the region been more thoroughly explored doubtless the limits of this system would have been much expanded and these three separate tracts would have been found to merge together in places. In fact, to make even the threefold grouping adopted it has been necessary to consider as parts of the same unit tracts that are by no means continuous but are interrupted by unexplored areas of considerable extent. Thus in the principal subdivision adopted, which includes the Brooks Range from the head of the John River westward to the Kivalina River, there are really seven more or less distinct sections into which the larger tract might be broken up to conform with the places where the most specific examinations have been made. These smaller subdivisions, which are readily apparent from the map (pl. 1), because of the greater continuity of geologic mapping shown in them, consist of the John River and Anaktuvuk River Valleys, the Killik River Valley, the Etivluk and Aniuk Valleys, the Noluk and Nimiuktuk Valleys, the Utukok and Kugururok Valleys, the western part of the Noatak Valley, and the Kivalina Valley. The other two principal areas of Carboniferous rocks in northern Alaska are in the western part of the Lisburne district and the central and eastern part of the Canning district.

Although showing marked local differences in detail, the Carboniferous rocks of the tract here referred to as the western part of the Brooks Range province have in general certain broad common characteristics. In the main in this tract the Carboniferous is divisible into two strongly marked types, which differ in lithology and in age. The older of these is dominantly a sequence of sandstones and shales to which the name "Noatak formation" (pl. 7, *A*) has been given, and the younger is dominantly a limestone formation called the Lisburne limestone. At the type locality of the Noatak formation, on the Noatak River near the mouth of the Nimiuktuk River, the rocks are medium fine-grained, rather massive sandstones with interlaminated shales that accentuate the bedding. In the section along the Aniuk and Etivluk Valleys the formation is made up of thin-bedded shaly sandstone, shale, and thin beds and lenses of white or bluish-gray limestone. Along the Killik River the section including this member consists of cherty and argillaceous beds and a curious chert conglomerate. In the John River section this formation, which is part of what was formerly called the †Fickett series, contains dark shale, schistose slate, and some dark limestone and is succeeded by quartzite, grit, and conglomerate. In all these sections the field evidence shows that the sequential deposition within the unit was not interrupted by marked movements of the earth's crust whereby breaks in the stratigraphy were produced. After these rocks were formed, however, they were subjected to intense earth forces by which the beds were uplifted, folded, and faulted, so that they are now greatly deformed. In fact, so intense has been this later folding that the structure of the rocks of this entire province is apparently composed of a series of overturned folds whose axial planes dip southward, though the regional dip is northward. In view of the complexity of the structure and the hurried studies of it, no reliable measurements of the thickness of this unit have been made. That it is thick is obvious from its mere width of outcrop, which in places as measured across the strike is 12 to 15 miles. Certainly its true thickness is to be measured in thousands of feet. Such fossils as have been collected from the Noatak formation belong to a Mississippian fauna, and the stratigraphic position of the beds beneath the richly fossiliferous Lisburne limestone, which is of late Mississippian age, corroborates that determination.

Along the northern flanks of the Brooks Range from the Anaktuvuk River westward, wherever studied, as well as at other places within the mountains, where folding or faulting has induced special structure, is a wide outcrop of the Lisburne limestone. In the vicinity of the Anaktuvuk River this formation is characterized by medium-bedded semicrystalline limestone of impure white or grayish color which weathers to a rusty brown or chocolate brown. In the Killik Valley the Lisburne formation, when viewed from afar off, appears to be a white limestone. When examined in detail, however, the beds near the top of the sequence are found to consist of innumerable layers of chert and limestone. In the lower part of the formation the bedding is somewhat more massive and the rock is a cream-colored crystalline limestone. In the valley of the Kugururok River the Lisburne formation is reported to consist of white to dark bluish-gray massive limestone with several exposures of black chert and a single outcrop of dark-gray sandstone. Silicification of the limestone is a common feature, and many of the limestone beds weather to a brownish red. In the Nimiuktuk and the Utukok and Aniuk Valleys the Lisburne limestone occurs in two bands separated from each other by an intervening wedge of much younger rocks. In these valleys, especially the easternmost, this formation consists mainly of pure white limestone. In the southern part of the valley of the Kivalina River the white limestone hills are prominent landmarks, and they can be traced by the eye eastward until they merge into the hills near the Kelly River, in the Noatak Valley, that are known to have the same bedrock. At places near Kivalina recrystallization has given the rock a streaked white color and a coarse crystalline grain, but usually the rock is dark brownish, with a light gray-blue appearance in weathered outcrop.

Locally the limestone is more or less silicified, but the process seems to have been effective long after the original deposition of the limy sediments of which the beds are composed and therefore to have affected the grains of the rock rather than its larger masses; as a result it did not produce rocks that resemble the cherts found in other parts of the Carboniferous system in northern Alaska. Many of the contacts of the Lisburne limestone with other formations are obscured by faulting, so that its precise relations are not determined with certainty. It is believed, however, that in this region there was no marked stratigraphic hiatus between the Noatak formation and the Lisburne limestone, and the Lisburne seems to have undergone comparable deformation by later stresses, so that it too has a complex structure. Not enough work has yet been done in northern Alaska to give a reliable estimate of the thickness of this formation, but it seems evident that where fully developed the thickness must be at least 4,000 feet. The age of this formation is now determined with considerable certainty from the several score collections of fossils that have been made from it. These fossils have been identified as distinctly of late Mississippian age, and this limestone, because of its wide extent and abundant and characteristic fauna, has become of especial significance in the correlation of all early Carboniferous rocks throughout the Territory. It gives a really impressive vision of the past to stand beside an outcrop of this ancient coral reef-making rock and realize that long ago it was a growing structure tenanted by those strange forms of sea life that existed in bodies of water and under climatic conditions so different from those of today.

The type area of the Lisburne limestone is at Cape Lisburne, in the extreme northwestern part of the district of that name (pl. 7, *B*). This limestone has been mentioned in almost all reports on that part of the coast, even in those of the earliest discoverers, because it forms striking landmarks, with its gleaming white cliffs that rise precipitously more than 1,000 feet above sea level and present unscalable fronts through most of the distance in which the formation abuts upon the sea. Thus Beechey, in the account of his voyage in 1826, wrote:

> It was fearful to look down upon the beach below. * * * The basis of the mountain was flint of the purest kind and limestone abounding in fossil shells, echinites, and marine animals.[21]

Less impressive, scenically, are black slates and shales that form three separate narrow bands but may be a single member reduplicated through faulting. These slates and shales form part of the Carboniferous system in this area and have been identified as comparable with the Noatak formation, principally because of their lithologic similarity and stratigraphic relations, but the determination of the definite age of these beds at Cape Lisburne rests on the evidence offered by the plant fossils they contain. These plants have been recognized by David White as representative of the early Mississippian flora, a determination that fits in well with the more general evidence from other sources. Unfortunately the outcrops of these lower beds are so disrupted by faulting that the original sequence of the sections is not determinable with certainty. It would be of great value if the transition could be traced more fully between these beds that were laid down under terrigenous conditions and the later limestone beds that were deposited in marine water. These beds contain several thin coal seams, some of which carry a high-rank bituminous coal that has been mined sparingly for local use. At the type locality this Lisburne limestone, as described by Collier, consists of massive thick-bedded limestone, massive chert, and a few thinner beds of black slate or shale, and at the nearby localities at Capes Thompson and Seppings it has similar characters. The formation is at least 2,000 feet thick and may be very much thicker. It has a complex structure, produced by open folding and thrust faulting. In places fault breccia and interstitial calcite make the rock resemble at a distance a coarse-grained porphyry, but no igneous rocks of that sort have been recognized anywhere in that neighborhood. Usually the limestone is abundantly fossiliferous, great coral heads and rubble resulting therefrom being especially conspicuous. A wealth of material from several points in the Lisburne district has enabled paleontologists to identify this limestone as Mississippian and to suggest that it probably occupies a rather high position in that part of the stratigraphic column.

The third principal known occurrence of Carboniferous rocks in northern Alaska is in the Canning district, in the extreme northeastern part of the region. The Carboniferous limestones in the valley of the Firth River and at other points adjacent to the international boundary have been mentioned on page 29. In the val-

[21] Beechey, F. W., Narrative of a voyage to the Pacific and Beerings Strait, vol. 1, p. 269, London, 1831.

leys of the Canning and Hulahula Rivers Leffingwell found a formation consisting of black slates, shales, and minor amounts of sandstone, which unconformably overlies the metamorphic schists. This formation is 1,000 feet or more thick. Definite determination of the age of this unit was not possible, but Leffingwell decided that it was Mississippian or Devonian. In view of the uncertainty as to its age, it has been shown on the accompanying map (pl. 1) as part of the undifferentiated Paleozoic or older rocks, but more complete field evidence will probably result in its being correlated, in part at least, with the Noatak formation farther west. Apparently, overlying this slate and shale member conformably, is a gray limestone that carries subordinate beds of black limestone near its base and is said to be the predominant rock in the northern part of the Franklin Mountains and their foothills. In places the limestone is much brecciated and has been recemented by white quartz, and there is abundant evidence of silicification throughout. Apparently the limestone thins toward the east, so that east of the Okpilak River its thickness is perhaps less than 1,000 feet, whereas in the Canning River Valley it is in places more than 3,000 feet thick. The general structure of the limestone in the Canning River district is a series of overturned folds striking about east and sliced by thrust faulting parallel to the trend. The limestone is abundantly fossiliferous. Colonies of corals, many of which consist of clusters 2 feet or more in diameter, are recognizable in most of the exposures. The age of the limestone has therefore been determined with much assurance from these organic remains, and they are so closely comparable with the fauna from the Lisburne limestone that the one formation name has been considered applicable to both. This limestone in the Canning River district is therefore called the Lisburne limestone and is assigned to the upper part of the Mississippian sequence.

Overlying the Lisburne limestone in the Canning district without recognizable structural unconformity is about 300 feet of light-colored sandstone or dark quartzite. The sandstone is fairly thick bedded and on exposed surfaces weathers to a dark rusty-brown color. The top of this assemblage of beds has not been recognized, so that its relation to the next younger formation is unknown, but no marked angular discordance between the two was discovered. This sandstone, which was called the Sadlerochit sandstone by Leffingwell, is said to carry abundant fossils in its lower part, near its contact with the Lisburne limestone. Its fauna differs from that of the older unit in that it consists dominantly of brachiopods rather than of corals, thus marking a pronounced faunal change. Originally, this fauna was referred to the Pennsylvanian, but with fuller insight into the general history of the Carboniferous gained through the added collections from that system throughout the territory, Girty is now convinced that it is more properly to be regarded as belonging to the Permian.

SEWARD PENINSULA

In a preceding section of this report (p. 24) reference was made to certain limestones in Seward Peninsula which were identified as being either Devonian or Carboniferous and which, because of that uncertainty, had perforce not been distinguished more specifically upon the map than being assigned to undifferentiated Paleozoic or older rocks. The only definitely recognized Carboniferous beds in the peninsula occur in the extreme western part in the York district, though it is by no means unlikely that elsewhere in the peninsula there may be members of this system which have not yet been discriminated from those of an earlier age. The known outcrop of the Carboniferous is described by Collier as a belt of crystalline limestone associated with interbedded mica schists and phyllites near Cape Mountain and the small native settlement of Palazruk. The limestone occurs in an area of strong deformation, and its original features are still further obscured by the fact that the beds lie near a large intrusive mass of granite, which has locally metamorphosed the beds. A few fossils have been collected from this limestone, but they were too imperfect for specific identification; however, Girty [22] states:

> Personally, I have scarcely a doubt that these fossils represent the same coral fauna that occurs in the Lisburne limestone, upper Mississippian, as against the Devonian coral faunas or the very deceptive Triassic coral fauna found in this region. This belief, however, is not capable of scientific demonstration on the material in hand.

The limestone is composed principally of calcite with some admixture of quartz. Its color is usually bluish to white, but in places it is nearly black. A few beds and lenses of sandstone and quartzite occur at intervals interbedded with the limestone, and secondary minerals that have obviously been formed through the metamorphic processes involved in the intrusion of the granite rocks here and there give variety to the more common appearance of the rock. At the extreme top of Cape Mountain the limestone appears to be overlain or replaced by fine-grained quartz schist abundantly sprinkled with dark mica flakes. The total thickness of the limestone has not been determined, because its lower part abuts against a fault of unknown displacement and its uppermost beds are cut out by the granite. However, at least 1,500 feet of beds can be seen, so that presumably its total thickness must be greater.

KUSKOKWIM REGION

Rocks that are definitely identified as belonging to the Carboniferous system have been found in the Kus-

[22] Girty, G. H., in Steidtmann, Edward, and Cathcart, S. H., Geology of the York tin deposits, Alaska: U. S. Geol. Survey Bull. 733, pp. 27–28, 1922.

kokwim region only in the Akiak district, near the mouth of the Aniak River, and in the Goodnews Bay district, in the extreme southwestern part of the region. This does not necessarily indicate the absence of this system elsewhere in the region, because much of the region is still entirely unknown geologically, and even the parts that have been examined have received but cursory study, so that close determination of the age of the rocks could not be worked out. There is therefore a strong likelihood that some of the areas now shown on the geologic map (pl. 1) as occupied by undifferentiated Paleozoic or older sedimentary rocks may, if studied more intensively, be found to contain representatives of the Carboniferous system. Among the more likely areas of this sort are the northern flank of the Alaska Range, the area north of McGrath, the highlands of the Georgetown district, especially in the Lime Hills and in their prolongation to the northeast and southwest, and the hills forming the divide in which the Tuluksak and Kiselalik Rivers and the western headwaters of the Aniak River rise.

The locality in the Akiak district where Carboniferous rocks have been found is on the north bank of the Kuskokwim River about 6 miles east of the settlement of Ohagamut. There this system is represented by limestones that appear to underlie and grade up uninterruptedly into layered effusive volcanic rocks. The light-gray color of the limestone makes it readily distinguishable for long distances in the landscape and thus a prominent horizon marker. The upper 25 feet of the section becomes increasingly tuffaceous, and the manner in which this material surrounds the crinoid stems, corals, and other fossil remains, strongly suggests that the tuff or volcanic ash fell on those organisms while they were still growing on the sea bottom. The fossils have been identified as belonging in the Permian, the uppermost division of the Carboniferous system. Limestones that appear to be more or less on the same line of strike as the one near Ohagamut are also reported in the highlands south of the Kuskokwim River, in the country tributary to the Tuluksak River. The relations of these limestones are so complicated that it was not possible for Maddren in the course of his hurried exploratory trip into that region to differentiate them from the other Paleozoic rocks, and so they have not been shown separately on plate 1.

In the Goodnews Bay district Harrington mapped certain rocks that lie north of the bay and west of the Goodnews River as Carboniferous(?) limestone with some red and black slates. The limestone is usually dark gray but weathers nearly white. Nodular chert was observed in some of the limestones, and other beds are intricately traversed by seams and veins of quartz and calcite. Overlying the limestone is a thick series of argillite, sandstone, and graywacke, which are locally considerably metamorphosed. No fossils were found in these rocks by Harrington, so that the determination of their age had to rest on general stratigraphic evidence and their similarity of appearance to other known Carboniferous rocks. However, in 1935, through the courtesy of Mr. W. G. Culver, a specimen was obtained of fossiliferous limestone from exposures in the hills northwest of Mumtrak. The fossils in this specimen were identified by Girty as characteristic of Permian beds, thus narrowing the limit set in the much earlier determination by Harrington, who had not gone farther than to suggest a Carboniferous age. As this determination by Girty has not appeared anywhere else in print, it seems appropriate to make his full statement available by quoting it here:

35AS102 (8010). Hill approximately 4 miles northwest of Mumtrak. Collector, W. G. Culver, 1935:

Productus (*Horridonia*) cf. *P. timanicus*.

Spiriferella arctica.

These fossils, though small and poorly preserved, can be referred with reasonable certainty to the Alaska Permian.

SOUTHWESTERN ALASKA

Nowhere in the great tract of country embraced within the southwestern Alaska region have Carboniferous rocks been recognized as such except in a small area in the Tikchik district, and it is extremely doubtful whether such rocks occur elsewhere in the region except in the contiguous Togiak district.

In the hills between Lakes Chauekuktuli and Nuyakuk Mertie found chert, conglomerate, quartzite, sandstone and a variety of argillaceous rocks including some limestone. The trends of these rocks show considerable range, but the average is about N. 77° W. The rocks, although folded and faulted, seem to have an average dip toward the south. The thickness of the succession of beds has not been determined with precision, but it is obvious that at least several thousand feet of strata are present. No fossils have been found in these beds, but their relations to known Permian beds led Mertie to correlate them with the Mississippian series.

In the Tikchik district two well-defined formations have been recognized as younger than these supposed Mississippian rocks. The lower of these is a limestone which is overlain conformably by a group of volcanic rocks. The limestone is cream-colored to yellowish and is more or less recrystallized. Its thickness is believed to be between 500 and 1,000 feet. Several collections of fossils from this limestone have been made, and the forms identified by Girty have been regarded by him as Permian. The volcanic rocks overlying the Permian limestone are predominantly of greenstone habit and include both lavas and tuffs. Some of the lavas have distinct bedding structure, and most of them show numerous gas cavities now filled with secondary minerals. The minimum thickness of this assemblage of rocks is stated by Mertie to be about 4,500 feet. The lower part of this unit grades without stratigraphic break upward from the Permian limestone through tuffaceous beds into the lavas. It is therefore necessary to consider the lower part Permian. The age of the upper part of this volcanic sequence, however, cannot be determined with much certainty, and it may be as young as the Triassic. Although admitting this possibility, Mertie has preferred to rely on the only definite evidence available and regard the volcanic rocks as mainly Permian. In other words, a close correlation is suggested between these volcanic rocks and the Nikolai greenstone of the Copper River region.

MESOZOIC ROCKS

The passage from the Paleozoic into the Mesozoic era in Alaska apparently was not marked by vast violent catastrophic upheavals whereby a spectacular break between the two ensued, for almost everywhere great angular unconformities between strata laid down in the two eras are lacking. The seemingly general unbroken sequence between the two is found on closer examination, however, to be only apparent, for there is an enormous hiatus between the youngest of the known Paleozoic rocks and the oldest of the Mesozoic sediments. The magnitude of this break will become more evident from the following descriptions, which show that except for one very doubtful occurrence no sedimentary rocks formed during Lower or Middle Triassic time have been identified at any place in Alaska. Thus a lapse of many million years is not represented in the stratigraphic column by any recognized sedimentary deposits, though some effusive rocks may have been poured out during that interval. The foregoing statement, although strictly accurate as expressing the present knowledge of the earliest part of the Triassic system, is not intended to imply that none of these early members will subsequently be found in the Territory, because large areas are still unsurveyed, and rarely even in the surveyed areas has the base of the Mesozoic section been seen in enough detail to prove the entire absence of sedimentary rocks older than the Upper Triassic. In fact, it is almost inconceivable that such quiescence prevailed that neither deposition nor notable erosion occurred during that long interval, and the geologist is so hard-pressed to give any satisfactory explanation of such a condition that he must await more complete information before attempting to construct a rational mental picture of that remote time.

Sedimentary deposits belonging to the Jurassic and Cretaceous systems are widely distributed through Alaska, and the Jurassic section exposed there is probably the most complete development of rocks of that age occurring anywhere on the North American continent. Marine and terrigenous deposits here and there alternate in this sequence, showing successive occupation of and withdrawal from different parts of the area by the oceans of the past. All the features of the region formed during the Mesozoic era wear increasingly an air of modernity that differs greatly from the aspects of the corresponding features in Paleozoic time. This condition, however, is purely relative, for it must be remembered that geologists, reckoning by data obtained from radioactivity, estimate that the most recent of the Mesozoic events took place probably more than 50,000,000 years ago and that the beginning of that era was perhaps 150,000,000 years still farther back in the past. Each of the three periods that make up the Mesozoic era is estimated to have spanned an interval of at least 30,000,000 years, and the most recent of them, the Cretaceous, may have been twice as long.

In the preparation of the following summaries of the published reports dealing with the Mesozoic deposits of Alaska the labors of the present compiler have been minimized by the scholarly and illuminating analysis made by G. C. Martin in his monographic treatment of the Mesozoic stratigraphy of Alaska.[23] That volume is indispensable to anyone wishing to know more about the details of this interesting era and its subordinate series and formations. Unfortunately, however, the volume was published more than 10 years ago, so that it does not include the results of some of the more recent investigations and the interpretations of some of the older information in the light of these more recent findings.

TRIASSIC SYSTEM

SOUTHEASTERN ALASKA

In southeastern Alaska at several places Triassic rocks have been found. At the different localities these rocks have varied characteristics which clearly indicate that they were formed under a wide range of conditions and through a considerable interval of time. Definitely identified sedimentary beds of the Triassic system have been found on Gravina Island, in the Ketchikan district; on Kuiu, Kupreanof, and smaller islands in Keku Straits of the Kupreanof district; in Pybus and Gambier Bays and between Mole and Windfall Harbors, in the Admiralty district, and in the Juneau district near the capital city. Rocks correlated with these definitely determined beds occur at several other places—for instance, on Revillagigedo, Annette, and Hotspur Islands, in the Ketchikan district.

At none of these places have the Triassic sedimentary beds been determined with a finality that permits close correlation between the different members in the widely separated localities. Martin has indicated a possible relative chronology for the beds at five of the principal areas in southeastern Alaska, but the table he prepared, though suggestive, has the appearance of rather more definiteness than seems entirely warranted by the known facts, and the writer has preferred to follow for the

[23] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, 493 pp., 1926.

present the less minute subdivisions by Buddington, who has done the most comprehensive field work on the general stratigraphy of the region and its various stratigraphic units.

According to both Buddington and Martin the only sedimentary rocks in southeastern Alaska that are recognized as Triassic belong to the Upper Triassic series, and no Middle and Lower Triassic sedimentary rocks have been found. The general stratigraphic column of the Upper Triassic, as determined by Buddington, appears to be divisible into two units, which are separated from each other by a marked unconformity. The lower of these units consists generally of conglomerate, sandstone, and limestone, and in its upper part in the Ketchikan district it includes considerable black slate. This unit is said to be best exposed on Gravina, Annette, and Revillagigedo Islands, the Keku Islets, the northwestern part of Kupreanof Island, Pybus Bay, Admiralty Island, and the Screen Islands. The thickness of this unit is estimated as about 1,600 feet. The upper unit of the Upper Triassic series consists of andesitic rocks, including breccia with limestone matrix, and lava flows which in part show pillow structure, locally interbedded with slates and other sediments. This unit is reported to be especially well exposed in the northwestern part of Kupreanof Island, including Hamilton Bay, on the northeast side of Kuiu Island; and on Hound Island, which lies midway between the other two islands. It has an estimated thickness of more than 1,400 feet. It is separated from the next overlying younger beds by a strongly marked unconformity.

Throughout southeastern Alaska the Upper Triassic rocks have been deformed into fairly close folds and broken by normal or thrust faults, so that their structure is complex, and their relations within themselves and to other formations show in many places apparently anomalous conditions. In spite of the strong deformation these rocks have undergone, it is usually apparent that, on the whole, they have experienced less intense stresses than the known Paleozoic rocks in the same general neighborhood. On the mainland and in nearby portions of southeastern Alaska, however, especially where it is likely that members of this system may have been involved not only in severe mountain-building movements but also in contact-metamorphic changes brought about through their close proximity to the great intrusive masses of granite of the Coast Range and offshoots therefrom, the normal characters of these rocks have probably been so greatly altered that it is no longer possible to identify them as Triassic. In such places these unidentified Triassic rocks are correctly shown on the map (pl. 1) as included in the undifferentiated Mesozoic sedimentary rocks or perhaps are incorrectly included in areas that are mapped as occupied dominantly by undifferentiated Paleozoic formations.

COPPER RIVER REGION

In the central part of the Copper River region—that is, in the Kuskulana and Nizina districts—is probably the most nearly complete and most satisfactorily exposed sequence of Upper Triassic rocks that is known in Alaska. The oldest or lowest sedimentary formation of that series has long been known as the Chitistone limestone, and it appears to rest conformably on a series of lava flows that are called the Nikolai greenstone (pls. 7, *C*, and 8, *B*). The lowermost of these lavas are known to have been extruded in the Permian epoch of the Carboniferous period, but as they embrace a series of rocks that is at least 5,000 feet thick the effusions may have continued well into Triassic time. Indeed, if the overlying Chitistone limestone is really conformable with them, the uppermost of these lavas may possibly be even as late as the Upper Triassic. The lowermost part of the overlying formation consists of bluish-gray limestone, most of it in rather thick beds and containing in places black chert in bodies of irregular form. Higher in the section beds of shale become thicker, although still much thinner than the limestone beds, and the proportion of limestone is less. On the basis of this change in lithology a different formation name has been given to this upper thinner-bedded, more shaly part of the section, which is called the Nizina limestone in distinction from the thicker-bedded, purer limestone, for which the name "Chitistone limestone" is retained. No stratigraphic or other break is recognizable between these two formations, the line between them being drawn on certain paleontologic evidence that is not yet thoroughly confirmed. The Chitistone limestone in the type locality is about 1,900 feet thick, and the Nizina limestone is about 1,100 feet thick. Still higher in the section the thin-layered limestone and alternating beds of shale of the Nizina limestone give place to almost uninterrupted shales, which have been called the McCarthy formation. This formation consists in its lower part of black shale and hard calcareous argillite in beds commonly less than 3 feet thick. In its upper part it is composed predominantly of black shale with only sporadic thin beds of limestone a few inches thick. The known thickness of the McCarthy formation is about 2,000 feet, but its uppermost beds have been removed by erosion, so that its full thickness has not been determined.

All these Triassic rocks are considerably folded, the more massive limestones, because of their strength, taking on larger-scale features, whereas the weaker shales, being less competant, have more minute and jumbled structure. Faults are abundant and have brought about mauy complex relations. Many of the faults are more or less parallel to the bedding planes of the limestone, so that slipping along the beds has been common. Fossils are as a rule not widespread in the lower limestone members, and where they occur they are usually not abundant. Collections have been made from more than a hundred localities, so that the general features of the formation have been fairly well determined. According to Martin, the fossil species *Halobia superba* is regarded as diagnostic of the Chitistone limestone, and *Pseudomonotis subcircularis* is the most diagnostic fossil in the McCarthy formation, but other geologists do not feel so thoroughly convinced of the specific diagnostic value of these forms. The faunas seem to indicate that the Chitistone limestone and part of the Nizina limestone were laid down in relatively warm ocean waters, whereas the upper part of the Nizina limestone and the McCarthy shales were deposited in much colder marine waters. The Triassic rocks were strongly eroded in places before the deposition of the next overlying formation, so that the top of this section is marked by a strong unconformity.

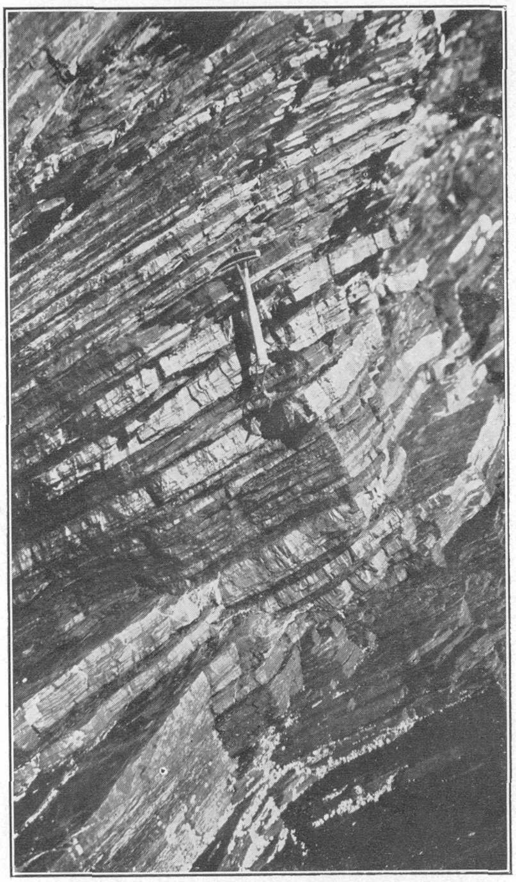
Rocks that have been correlated by some geologists with the Triassic system have been reported at other points in the Copper River Valley and in adjoining parts of the tributary streams of the Tanana River Valley, which rise on the northern flanks of the Alaska Range. Some of these correlations have not yet been generally accepted or affect only areas so small that they have not been shown on the accompanying map. One of these areas is near the terminus of Russell Glacier, east of the pass between the Nizina and White Rivers. Here occur shales, lavas, and pyroclastic rocks which Martin suggests may be the equivalent of the McCarthy formation, though Moffit and Capps had not mapped them separately from the rocks that are dominantly of Carboniferous age. About 10 miles west of Skolai Pass, near Nizina Glacier, Moffit found definitely identified Triassic black shale carrying a characteristic Chitistone fauna, unconformably overlying Permian rocks. Farther north in the same geologic province, though outside the limits of the Copper River drainage basin, on the southern slopes of the Nutzotin Mountains between the Nabesna and Chisana Rivers, are outcrops of rather thin-bedded limestone and some black shale. At Cooper Pass in this area *Pseudomonotis* fossils were found which clearly indicate that Upper Triassic rocks occur there, though they were not differentiated in the field work, and their areal distribution cannot be mapped. Moffit and Knopf originally correlated these beds with the Chitistone limestone, but Martin later suggested that, owing to the presence of *Pseudomonotis*, they may belong in the McCarthy formation.

COOK INLET-SUSITNA REGION

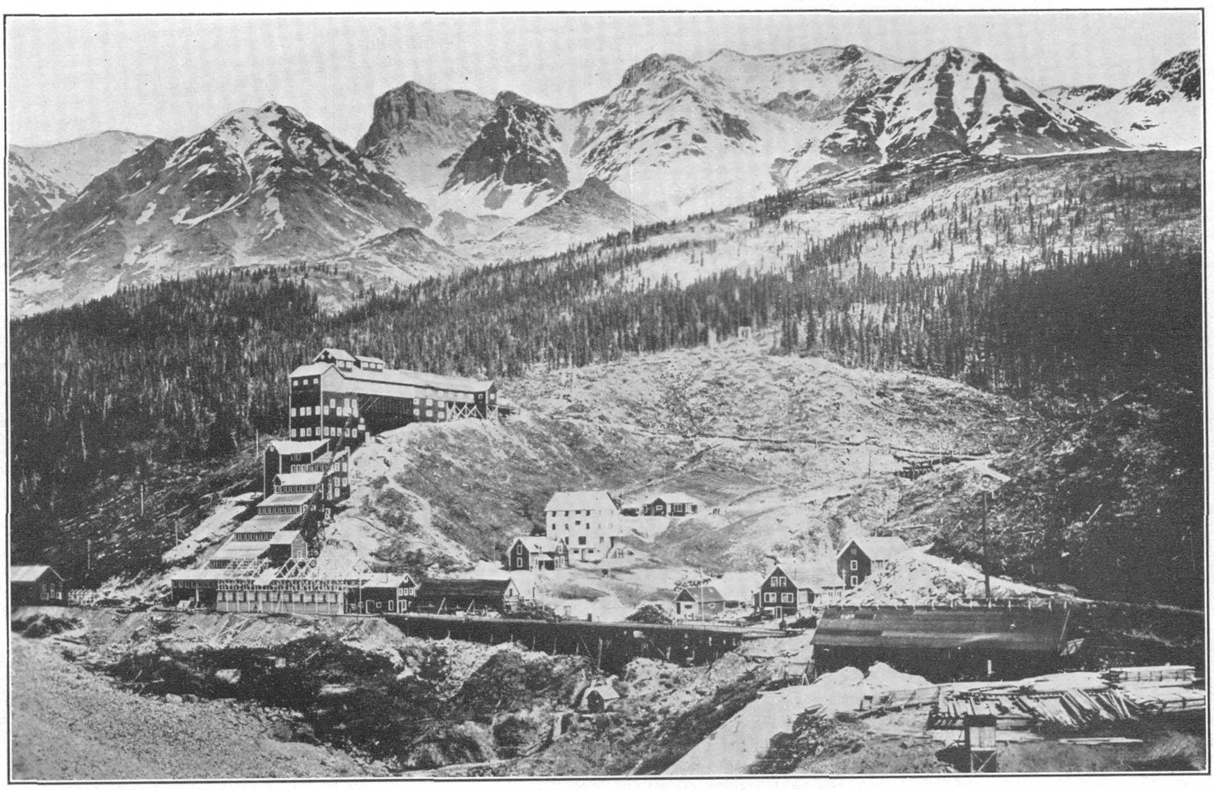
Members of the Triassic system have been recognized in widely separated districts in the Cook Inlet-Susitna region. These districts, named from north to south, are the Valdez Creek, Chulitna, Chinitna, Kamishak, and Seldovia districts. This system has thus been identified as extending more or less interruptedly for a distance of nearly 350 miles in this region. Necessarily there is considerable variation in its details throughout this distance, though its general characteirstics remain fairly constant.

In the Valdez Creek district a belt of Triassic rocks about 5 miles wide extends westward from a point near the mouth of Valdez Creek. Thence, swinging more to the southwest, it has been traced as far as Deaman Creek, beyond which lies country that has not been surveyed. Limestone that possibly belongs to the same system is reported by Capps in the heart of the Talkeetna Mountains, near the eastern margin of the belt of greenstones that is mapped there. These limestone beds, however, occupy too narrow a belt to be shown on the accompanying map. In the eastern part of the main belt of Triassic rocks in this district the beds are predominantly thin-bedded shaly limestone and calcareous sandstone, which have a complex structure owing to the deformation and intrusion to which they have been subjected. Farther west the section seems to consist more dominantly of dark-blue and black slates, with some interstratified arkose and graywacke but almost no limestone beds. All the Triassic rocks are considerably folded and dislocated by faulting. Because of difference in the fossils they contain Martin concluded that the limestone beds are older than the shaly beds and are comparable in age with the Chitistone limestone of the Copper River region, whereas the higher beds may best be correlated with the McCarthy formation.

In the Chulitna district Ross distinguished two principal lithologic facies of the Triassic system—namely, limestone at the base, and a great thickness of argillaceous rocks above. The limestone part of the section shows at its base thick white limestones, somewhat crystalline, above which are sandy rusty limestones. Associated with these higher beds are numerous thin beds of argillite and somewhat impure sandstone. The total thickness of this group of limestones and associated beds is in places as much as 2,000 feet. Fossils have not been found in the crystalline member of the sequence but are widely distributed in the rusty limestone. The younger member of the Triassic system rests conformably on and grades upward from the more limy beds. In general, it is composed of black argillite and argillaceous sandstone, but some lenses of tuffaceous and pyroclastic material are interbedded with the shales, and near the eastern border of the area there are lenses of well-worn conglomerate, some of which have pebbles as much as half an inch in diameter. No fossils have been found in these argillites, and their geologic age cannot be determined with precision. Their apparent conformity with the underlying limestones, which are definitely known to contain an Upper Triassic fauna, and their general similarity to known Triassic rocks elsewhere in Alaska constitute the basis for regarding them as Triassic also, but as the argil-

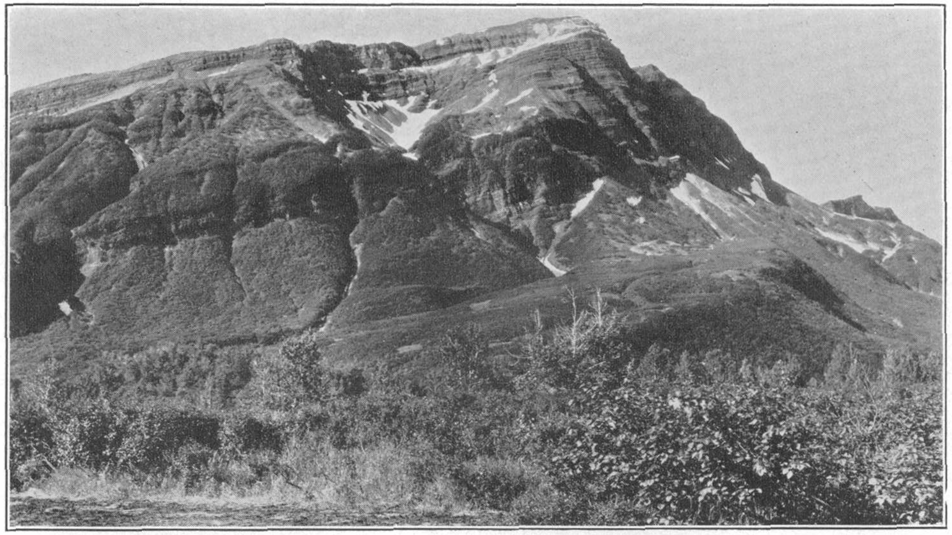


A. ALTERNATING LAYERS OF CHERT AND SHALE IN SECTION OF UNDIFFERENTIATED MESOZOIC ROCKS EXPOSED ON KODIAK ISLAND.

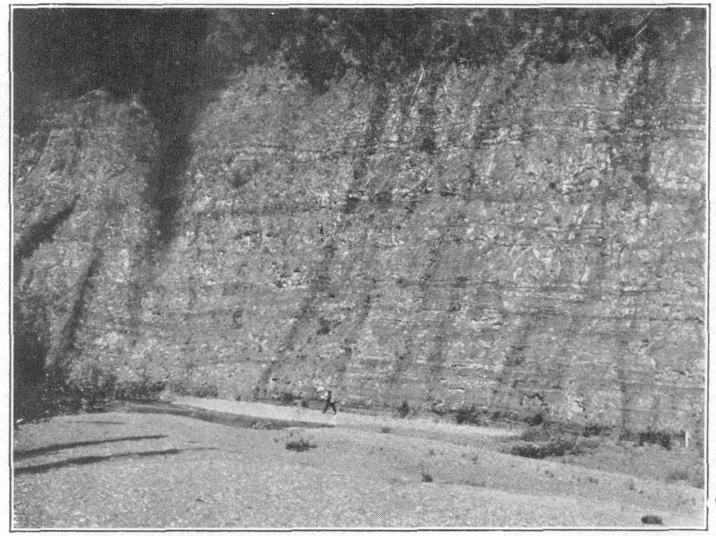


B. TRIASSIC AND ASSOCIATED ROCKS IN THE VICINITY OF KENNECOTT P. O., IN COPPER RIVER REGION.

Near the site of the greatest copper-producing mines in the Territory.



A. GENTLY DIPPING SANDSTONES AND SHALES OF JURASSIC AGE IN VALLEY OF JOHNSON RIVER NEAR MOUNT ILIAMNA.



B. FLAT-LYING SHALES OF SHAKTOLIK GROUP, OF UPPER CRETACEOUS AGE, IN VALLEY OF SHAKTOLIK RIVER EAST OF NORTON SOUND.

C. JUNEAU, CAPITAL OF ALASKA, AND MILL OF LARGEST GOLD-MINING COMPANY IN THE TERRITORY.

The deposit that furnishes the ore consists of a great number of quartz veins in late Mesozoic slates and graywackes that lie not far west of the great Coast Range batholith.

lites are part of a thick sequence of beds, it is by no means unlikely that their upper part may belong to a younger geologic system.

In the Chinitna and Kamishak districts Triassic rocks are represented in the vicinity of Iliamna Bay and in adjacent areas in the vicinity of Lakes Clark and Iliamna. The rocks that are correlated with this system consist of limestones and possibly of some volcanic rocks. The limestone beds are not extensive areally because they are interrupted and cut off by intrusive masses and rocks of igneous origin. Because of their small extent several of these areas in which the limestones crop out are not represented on the geologic map (pl. 1). Although fossils have been obtained from some of the limestone beds, they have not enabled paleontologists to determine with certainty the age of the beds because they are completely unlike any known Triassic or Paleozoic fauna from Alaska or, indeed, from any other part of North America. Apparently these fossils have nearest affinities with certain of the Triassic faunas from the European Alps, which are assigned to the upper part of the Triassic system. The section of these rocks in the Chinitna district is incomplete, so that no measurement could be made of its full thickness; but from the meager information available the limestone must be at least several hundred feet thick.

In the vicinity of Bruin Bay and Ursus Cove, as well as at other points in the Kamishak district, the uppermost formation of the Triassic sequence consists of cherts and related rocks, to which the name "Kamishak chert" has been given. This formation consists of 2,000 feet or more of dark chert occurring in rather thick beds, interstratified with thin layers of shale, sandstone, and limestone. In the lower part of the section there is considerable igneous material, some of which is intrusive. The beds are much contorted and in places are dislocated by faults. The lower, more cherty members have yielded no fossils, all the fossils so far collected having come from the upper 1,000 feet or so of the formation. These collections contain *Pseudomonotis*, the characteristic Upper Triassic pelecypod, so that correlation of the beds with the McCarthy formation is indicated. The Kamishak chert lies above the Triassic limestone member.

The Triassic rocks in the Seldovia district are exposed as a narrow band along the east shore of Kachemak Bay from a point near Port Graham northeastward to a point near the head of the bay. The Triassic section at this place, according to Martin, consists of contorted cherts overlain by limestone and tuff. The chert member consists of thin even-bedded hard siliceous layers as much as 2 inches thick, separated by thin films of softer, probably argillaceous material. The beds are so intensely deformed and crumpled that the general structure is not determinable, but apparently they rest on ellipsoidal lava that Martin states may be analogous to the Nikolai greenstone of the Copper River region and may itself be of Triassic age. The chert formation, however, has yielded no fossils, so that its age has been determined only from general stratigraphic evidence, especially such as is afforded by the relation of the chert to the overlying fossiliferous Triassic limestone. These overlying beds consist of limestone with considerable amounts of chert and fine-grained volcanic material, which is mostly tuffaceous. The Triassic beds are considerably folded and faulted, so that it is impossible from the data in hand to determine their true thickness, but at least 1,000 feet of strata are included in this unit. The presence of *Pseudomonotis* in the upper part of the section indicates that these beds are probably closely comparable in age with the McCarthy shale of the Copper River region, and the presence of *Halobia* lower in the section gives some basis for correlating that part with the Chitistone limestone of the same region.

SOUTHWESTERN ALASKA

Southwest of the Kamishak district the Triassic sedimentary rocks are definitely recognized only in the vicinity of Cold and Alinchak Bays, in the Kanatak district, though possibly other localities might be discovered if the intervening region were more thoroughly explored. In this area the beds that have been assigned to the Triassic consist in their lower part of contorted chert, in which no fossils have been found. The chert is overlain by limestone and shale. This sequence rests on basic igneous rocks whose age has not been determined but which may themselves be Triassic, though a Paleozoic age seems more likely. At Cape Kekurnoi the Triassic section includes about 700 feet of limestone and shales dipping about 20°. These beds are overlain by less calcareous shales that Martin considers may be Triassic, though he believes it more likely that the change in lithology also marks the passage from the Triassic to the Jurassic system. The common diagnostic fossil of the Triassic rocks in this district continues to be *Pseudomonotis subcircularis*, though a few other forms have been found in these beds.

In the western part of the region, in the Tikchik district, Mertie reported the occurrence of small outcrops of Triassic rocks on the south shore of Lake Nuyakuk. At this place the recognized Triassic rocks consist of white to cream-colored limestone entirely recrystallized at the westernmost outcrops and dark-gray finely crystalline at the eastern ones. Some pebbly beds occur in the sequence. All the beds have evidently been affected by faulting so that their relations and structure were not determinable and consequently no true idea was obtainable as to the thickness of the unit. The fossils collected from the limestone were identified as Upper Triassic, the form *Pseudomonotis subcircularis* being especially characteristic of these beds, as well as of the Upper Triassic throughout Alaska.

Rocks resembling the cherty phase of the Triassic system have been reported in the vicinity of Uyak and elsewhere on Kodiak Island (pl. 8, *A*). Although it is possible that members of this system may be distinguished there by more detailed work, Capps, who examined this region in 1935, reported that the absence of diagnostic fossils in the rocks and the complexity of the structure make close correlation on lithologic grounds hazardous, and that he considered it unwarranted at this time to date any of the sedimentary rocks in the general vicinity of Uyak more closely than in the Mesozoic era.

YUKON REGION

Throughout most of the great interior province of Alaska Triassic rocks are practically unknown. As noted in the section dealing with the Copper River region, some Triassic beds have been recognized in the Alaska Range, which forms the watershed between the Yukon Valley and that of the Copper River. The Triassic rocks in the White River and Chisana districts, which are tributary to the Yukon Valley, are described on page 36. The only other places within the limits of the Yukon drainage basin where Triassic rocks have been recognized are in the Kandik and Sheenjek districts. The occurrence in the Sheenjek district has not been studied in the field by members of the Geological Survey, but definitely determinable Triassic fossils have been collected there by a prospector, who states that they were obtained from rocks in the Coleen Valley in about the latitude of Helmet Mountain, a mapped landmark in the Sheenjek Valley.

In the Kandik district the Triassic rocks are exposed near the mouth of the Nation River and in the valley of Trout Creek, about 12 miles farther upstream to the east. At the Nation River locality the Triassic rocks crop out on both sides of the Yukon River, though the most nearly complete section is exposed along the southwest bank. These rocks rest on the Permian limestone without angular discordance, though probably separated by a great time interval. They consist of thin-bedded limestones and calcareous shale and appear to be less crystalline than the Carboniferous beds on which they rest. As the top of the Triassic sequence is not exposed, the total thickness of the members of this system here is not determinable, but the known part embraces a thickness of at least 400 feet. The section of Triassic rocks exposed at the Trout Creek locality consists of thin-bedded shaly limestone and black shale at least several hundred feet thick. The shale is a mat of closely compressed fossils in a black shaly matrix. This rock is of special interest because of its bituminous content, which is so high that the shale qualifies as a rich oil shale capable of yielding perhaps 25 to 30 gallons of oil from a ton of the rock. Microscopic examination of the shale shows that the bituminous material is derived from the countless spores it contains. A score or more collections of fossils from the Triassic beds of the Kandik district, especially those near the mouth of the Nation River, have afforded a fairly large and representative fauna. The older of these forms are mostly ammonites, which are limited to the lower beds of the sequence. In the higher beds *Halobia*, *Pseudomonotis*, and many other typical Upper Triassic forms are abundant.

A doubtful occurrence of Triassic rocks in the Yukon region is that reported by Capps in the part of the Kantishna district lying on the northern slope of the Alaska Range, at the head of the Sushana River, which is a tributary of the Kantishna River, itself a tributary of the Tanana River. Here, in a small outcrop of black siliceous limestone, some poorly preserved corals were found. These were examined by T. W. Stanton, who stated that they seemed to be of Mesozoic types, though he could not identify them even generically, and that their similarity to some of the corals found in other Triassic rocks of Alaska led him to believe that they were probably of that age. The uncertainty that surrounds this identification and the extremely small areal extent of the outcrop of these rocks as known in that district have led the writer to omit the indication of this locality on plate 1.

NORTHERN ALASKA

Members of the Triassic system have been recognized in practically every one of the districts of northern Alaska from the international boundary westward, and doubtless further exploration of this little-known region would add materially to the number of these occurrences and to the area that is represented as marking the outcrop of these rocks. The easternmost of the Alaska occurrences in this province is in the Canning district, in the valley of the Firth River, near the international boundary. The rocks at this place consist of impure limestone and sandy shale having a thickness of at least several hundred feet and possibly more than 1,000 feet. Neither the top nor the bottom of this sequence of beds is known, so that the total thickness of the beds representing the Triassic system could not be determined. The formation has been involved in folding so intense that in places it has been overturned, and older beds appear to lie on top of younger ones. The presence of *Halobia superba* and *Pseudomonotis subcircularis* in the fossil collections made from these exposures led Martin to suggest the possibility of two distinct faunal zones, that marked by *Halobia* being the older, but in the absence of definite field evidence as to the structural relations between the two, this can be regarded as only a helpful working hypothesis.

In the valley of the Canning River, some 125 miles west of the international boundary, Leffingwell discovered Triassic rocks which he designated the Shublik formation. This formation comprises three rather distinct lithologic units—the lowermost member consisting of calcareous sandstone about 30 feet thick; the intermediate member, composed of limestone and some interlayered shale, having a thickness of about 100 feet; and the uppermost member, composed of black shale, also about 100 feet thick. In the section are intervals in which the bedrock is not exposed but which, if filled, would make the total thickness of the beds belonging to this system about 500 feet. The fossils contained in these rocks clearly belong to an Upper Triassic fauna, but they differ markedly from the better-known Triassic faunas of the more southern parts of Alaska, in that corals are entirely absent and there is a dearth of the usual ammonites. According to Martin this fauna is more nearly comparable to that in the lowermost beds of the Triassic limestone in the vicinity of the Nation River, in the Kandik district of the Yukon region.

Triassic rocks have not been recognized on the northern flanks of the Brooks Range in the Anaktuvuk district. This lack of recognition, however, is believed to be due more to the necessarily hurried manner in which the exploration of the area where these rocks are likely to occur was performed than to the actual absence of these rocks. Less than 30 miles to the west of the Anaktuvuk River Triassic rocks were identified, and from that point westward all the way to the Arctic Ocean near Cape Lisburne these rocks were found in the different sections across the northern flanks of the mountains and in the Noatak Valley. The Triassic rocks in the vicinity of the Killik and Chandler Rivers, in the eastern part of the Colville district, form a belt 5 to 8 miles wide and consist of chert, thin-bedded limestone, and a siliceous dark-colored but white-weathering argillite.

Excellent exposures of the Triassic rocks were found in the valley of the Etivluk River about 30 miles upstream from its junction with the Colville. Chert is the outstanding component, though sandstone, shale, and limestone are not uncommon. The rocks show great variation in color, ranging from nearly pure white, through blue, black, green, and red, and some of the colors are characteristic of beds 20 feet or more in thickness. Spherical bodies of dark crystalline calcite from 1 to 6 inches in diameter, showing distinct radial structure, are found at several horizons in the chert. A few small crystals of pyrite occur in the calcite.

Sandstone and shale constitute the major part of the Triassic sequence at the heads of the Utukok and Colville Rivers, but there is a large amount of chert in beds from 2 to 5 inches thick. In general this chert weathers to a light olive-green color, which serves to distinguish it from the black chert usually associated with some of the Carboniferous beds that occur in the same neighborhood. The section consists of about 1,000 feet of strata, in which the lower part is composed of sandstone and the upper 150 feet or so becomes increasingly cherty, with some thin limestone beds.

In the Kivalina, Kukpuk, and Kukpowruk Valleys the most distinctive feature of the Triassic rocks is the chert, which weathers into fantastic pinnacles. Subordinate amounts of sandstone and shale accompany the chert in the lower part of the section in this area and are overlain by several hundred feet of light-colored and silicified and cherty limestone, which in turn is followed by thin-layered limestone. The limestone is dark chocolate-colored and has numerous light-colored trails of worms on its surface. Above this limestone is 100 feet of thin-splitting dark tenacious shale full of vegetable material.

One of the earliest recognized localities for Triassic rocks in Alaska is that near Cape Thompson, in the Lisburne district, and later the same system of rocks was recognized at three other localities in the vicinity of Cape Lisburne. At Cape Thompson, above a massive outcrop of Carboniferous limestone, there is an abrupt lithologic break, the succeeding 600 feet consisting of argillite with bands of black, green, and red chert. This member is succeeded by 25 feet of dark chert and thin-bedded cherty limestone with some greenish bands which contains Upper Triassic fossils. The upper 7 feet of this unit is composed almost exclusively of shells that have been altered to chert. Next above these beds is 500 feet of soft black shale that may be Triassic or younger. The sequence in the vicinity of Cape Lisburne is so much interrupted by faulting and deformation that it is much less complete, but apparently it includes representatives of many of the same kinds of rocks as those at Cape Thompson.

In the Noatak Valley Triassic rocks were found in the central part, near the mouth and the head of the Nimiuktuk River, near the Aniuk River, and at the head of the Kugururok River. At the outcrops near the Nimiuktuk River the beds consist of slaty material and thin-bedded greenish chert which contains large cubes of pyrites. Similar rocks occur also at the head of the Nimiuktuk, in the divide between that stream and the headwater tributaries of the Nuka River, of the Colville drainage basin. This band is about 3 miles wide across the strike and is separated from the wider band of Triassic rocks to the north at the heads of the Utukok and Colville Rivers. This narrower band probably extends westward and is continuous with the Triassic rocks at the head of the Kugururok River and is near the divide between that stream and the Utukok River.

All the Triassic rocks in the western part of northern Alaska have been highly deformed and faulted. Indeed, the observed structure of these rocks is so complex and involved that complete reconstruction of their structure is impossible. Vertical dips and even overturning of the beds are the rule rather than the exception. It seems certain that in general these Triassic rocks have been involved in the same great mountain-building deformations as the Carboniferous rocks and, like them, form part of a great structural feature in which the beds become progressively younger toward the north, but the details of structure are not known and must await more intensive field examinations.

Practically the only fossil that has been recognized in the collections made from these rocks in the western part of northern Alaska is *Pseudomonotis subcircularis*, which is considered characteristic of the higher part of the Upper Triassic fauna. Undoubtedly the meagerness of the fauna collected is due to the conditions under which the field work was done, whereby only cursory examinations could be made in the course of the explorations, so that a much richer fauna will probably be found when adequate investigations are carried out. Indeed, the thickness of the known sequence of the Triassic rocks is so great as to indicate that it may include much more of the Triassic section than is represented by this rather late fauna.

SEWARD PENINSULA

A puzzling and perhaps an erroneously reported occurrence of Triassic rocks in Seward Peninsula is the only indication of such rocks in that region. In 1908 Kindle received a specimen containing numerous fossils that was said to have been collected from an area of black slates on the southern slopes of Brooks Mountain, in the York district. The specimen apparently was not broken out of the rocks in place, and the original collector is unknown. These fossils have been identified by Stanton as definitely of Middle Triassic age and are said to be the only representatives of that fauna that have ever been found in Alaska. The only sedimentary rocks that have been recognized in place in the vicinity of Brooks Mountain (and considerable work has been done there) are Mississippian or older. It is possible, of course, that some unidentified Triassic rocks have been infolded or infaulted into these older rocks, but the writer is of the opinion that such an explanation is extremely unlikely. He is inclined to believe that the Middle Triassic specimen in question did not come from Seward Peninsula at all, or even from Alaska, but was a chance specimen whose place of origin was mistakenly confused by the assayer who gave it to Kindle. At any rate, the areal extent of rocks that might be of Triassic age in this part of Seward Peninsula as at present recognized would seem to be too small to be represented on the accompanying map.

Martin has noted the occurrence of a boulder containing Triassic fossils on St. Lawrence Island, in Bering Sea about 150 miles southwest of Nome. Although it is possible that this boulder was derived from Triassic beds that may form the bedrock of parts of the island, it seems more likely to have come from a more remote source. In fact, the general direction of the drift of the ice through Bering Strait would strongly suggest that agency as effecting the transportation and deposition of foreign boulders in this locality.

JURASSIC SYSTEM

The development of Jurassic rocks in Alaska is notable—in fact, the most complete sequence of these rocks on the North American continent is to be seen in this Territory. In the main, the outcrops of the sedimentary rocks of this system are closely confined to the country adjacent to the shores of the Pacific Ocean in southeastern Alaska, the southern Copper River region, the Cook Inlet region, and the Alaska Peninsula section of southwestern Alaska. No exposures of these rocks are known in the central interior country, to the north of the Alaska Range and south of the Brooks Range, and the distribution of Jurassic rocks to the north of the Brooks Range is but imperfectly known. Although Jurassic sedimentary rocks have been identified at different places in the southern areas mentioned, only in that part of the Alaska Peninsula from Tuxedni Bay southward to Chignik have the rocks been sufficiently distinguished from the other Mesozoic rocks with which they are associated or is the area occupied by them of sufficient extent to be represented on plate 1. For the first of these reasons it has been necessary to include the Jurassic rocks with the group of undifferentiated Mesozoic sedimentary rocks, though the individual occurrences will be described briefly in the following pages in the same geographic order that has been adopted for the other systems.

SOUTHEASTERN ALASKA

The rocks in southeastern Alaska that are now regarded as of Jurassic age, in part at least, include several distinct lithologic varieties and have been formed by various geologic agencies. Buddington has divided the layered rocks into two main groups, of which the older was formed dominantly through volcanic activity and consists of schistose greenstone, mainly hornblende and less commonly augite porphyry, and breccia, with intercalated tuffs and flows, black slate, and graywacke, and the younger group is predominantly sedimentary, consisting of graywacke, black slate, and conglomerate. It should also be remembered that the Jurassic is the period in which many of the great batholithic intrusions began, so that intrusive rocks formed during that time are now widely exposed at the surface and form some of the most notable geologic features of the region.

In the Juneau district (pl. 9, *C*) the †Berners formation and comparable assemblages of beds have considerable areal extent along the east coast of Lynn Canal and extend southward to include part of Douglas and Admiralty Islands. This assemblage is composed mainly of slate and graywacke, with some greenstones that are now regarded as of Jurassic or Cretaceous age. In the vicinity of the old Treadwell mine a black slate with some conglomerate and much graywacke, which is overlain by volcanic rocks and underlain by another volcanic group, is regarded by Martin as probably of Upper Jurassic age. A belt of rocks of similar lithology and structure borders Seymour Canal, the western part of Fanshaw Peninsula, and part of the north end of Kupreanof Island. Still farther south, in the Mitkof and Etolin Islands area, the same general belt of rocks continues as fine-grained foliated, more or less fissile graywacke, with slate partings. Small lenses of limestone occur at intervals in this sequence of beds. On Chichagof Island slate and graywacke beds that may be either Upper Jurassic or Lower Cretaceous were found by Overbeck in the vicinity of Slocum Arm. In the Ketchikan district a sequence of greenstones and slates on Gravina Island and adjacent areas has been doubtfully referred to the Jurassic, though the paleontologic evidence on which this assignment was based is admittedly inadequate, as in the identification of the fossils from these beds Stanton specifically stated that they were "probably Upper Jurassic but possibly Lower Cretaceous."

Martin, in his discussion of the age of this general series of rocks in southeastern Alaska, seems to have attached considerably more value to certain lines of evidence than appears warranted in the experience of those who have made the most extended field studies in that region. For instance, the presence of pebbles of granitic rocks in certain beds is used by Martin as a rather definite criterion that the age of those beds is later than the Jurassic. As stated in a preceding section of this report, granite boulders and cobbles have been recognized in other beds in this general region that are definitely of Silurian age, so that there were evidently intrusions of rock of this type earlier than Jurassic time, and that line of evidence therefore seems less cogent than Martin believed. Accordingly the age of the Mesozoic beds that contain granite pebbles is not definitely precluded from being older than Cretaceous.

COPPER RIVER REGION

Near the mouth of the Chitina River, in the central part of the Copper River Valley, is a massive conglomerate whose well-rounded pebbles consist of argillite, greenstone, diorite, and quartz in a tuffaceous matrix. This sequence rests unconformably on the underlying Paleozoic rocks and in turn is overlain without noticeable stratigraphic break by fossiliferous tuffaceous slates of the Middle Jurassic. No fossils have been found in the conglomerate, so that its age must necessarily be determined from less precise lines of evidence. Moffit, on the basis of its close relation to the Middle Jurassic rocks, concluded that the conglomerate was probably the basal division of that series. Martin, impressed with the difference in lithology from the Middle Jurassic rocks of other parts of Alaska, suggested the possibility of assigning it to the Lower Jurassic, though he stated that the evidence in hand does not justify placing these beds more definitely than in the early part of the Jurassic, in either the Middle or the Lower Jurassic epoch. The tuffaceous beds above the conglomerate are dark fine-grained sandstone-like rocks, which are slightly calcareous and show numerous small flakes of mica on the fracture planes. Several collections of marine fossils have been made from these rocks, which have been identified as of Middle Jurassic age and essentially equivalent to the Tuxedni sandstone of the Cook Inlet region, described on page 42.

Near Fourth of July Pass, northwest of Kennecott, is a series of conglomerates, sandstones, limestones, and shales which was originally called the Kennicott series and later Kennicott formation and assigned to the Upper Jurassic. As investigations have proceeded and more fossils have been available for comparison, it has become apparent that the assemblage is much more complex than was at first supposed, inasmuch as it embraces rocks whose ages range from Triassic to Cretaceous. Various attempts to separate the members of the different systems have not yet cleared up the confusion. In fact, some additional confusion has arisen because, as at present defined, the Kennicott formation includes only certain members of a rather indefinite sequence of Lower Cretaceous rocks. All that can now be said as to the presence of Jurassic rocks in this part of the Copper River Valley is that Moffit has found definite Jurassic fossils in rocks formerly designated Kennicott that are indistinguishable from the surrounding Cretaceous rocks. Until further field work is done it will be impossible to differentiate the two systems on the map. It may be of interest to note that the early determinations of the age of this formation were based upon both plant and animal fossils, but the Moffit collections, referred to as definitely Jurassic, contained only marine invertebrates.

The Nutzotin Mountains, though in the main within the drainage basins of the tributaries of the Tanana River and thus properly included in the Yukon region, are usually considered part of the Copper River province because of their proximity to it and because they are most readily reached by way of the routes through that province. In these mountains there is a great thickness of Mesozoic sediments that, in part at least, are of Jurassic age. Complex structure and metamorphism, as well as lack of detailed studies, make it impossible at this time to state with finality the exact characteristics of representatives of this system. Apparently a large part of the sparingly fossiliferous slate and graywacke that form the greater part of the Nutzotin Mountains is Jurassic and probably occupies a position near the top of that system. The black shales in the vicinity of Jacksina Creek are considered by Martin to form the highest member of this system known in this region. Originally these rocks were called the Nutzotin "series", but that name has fallen into disuse because of the indefiniteness of the limits assigned to it. These rocks grade upward without recognizable stratigraphic break into rocks that are similar lithologically but contain fossils that are definitely of Cretaceous age. It is therefore evident that although Jurassic rocks unquestionably crop out in the Nutzotin Mountains and their environs, their differentiation from rocks of other systems has not been made with enough exactness to permit representation of the area they occupy on the accompanying map (pl. 1), and they have therefore been included in the group of undifferentiated Mesozoic sedimentary rocks.

COOK INLET-SUSITNA REGION

Rocks that are known to belong to the Jurassic system in the Cook Inlet-Susitna region are shown on the accompanying map in the Chinitna, Kamishak, and Seldovia districts only, but at other places within this region there are representatives of this system that are not shown either because they have not been fully differentiated from other Mesozoic rocks or because they have too small areal extent. Practically all the districts of this region contain rocks that may belong to the Jurassic system, and the individual places mentioned in the following notes are those in which the better-known or more extensive deposits occur.

The oldest of the Jurassic rocks in the Seldovia district of Kenai Peninsula appear to be tuff and volcanic agglomerates interbedded with thin strata of limestone, shale, and sandstone. These rocks are exposed along the west coast of the peninsula from the vicinity of Point Bede to Seldovia Bay. Marine shells are common in the sedimentary beds, and the absence of noticeable breaks between these beds and the tuffs and agglomerates strongly suggests that the entire assemblage of rocks may have been deposited in marine waters. The tuff and volcanic portions of the section has considerable range in chemical composition, as in different parts it shows fragments of rhyolite, andesite, and quartz keratophyre. The structure of the beds is in the main simple, the dominant dip being monoclinal to the northwest. This structure is evidently dislocated by later faulting of the normal type, so that some duplication of beds has been effected. As neither the top nor the bottom of this group of rocks has been recognized, no measurements of its total thickness can be given, but the estimated thickness of the known part of the section is at least 1,000 feet and possibly is nearer 2,000 or 3,000 feet. Only relatively small collections of fossils from these beds have been made, so that their exact position in the system cannot yet be determined with finality. However, in the opinion of Stanton, who has examined all the collections, the fossils seem to belong to one general fauna which he regards as Lower Jurassic.

Possibly some Jurassic strata may be included in the thick sequence of undifferentiated Mesozoic sedimentary rocks that forms the greater part of Kenai Peninsula and extends into the Alaska Gulf region, especially in the Latouche, Port Wells, Valdez, and Cordova districts, but if so, there is no definite evidence of it, and such positive evidence as is available from the few scattered fossils that have been found indicates a Cretaceous age for part of these rocks. However, the enormous width across the strike of the area occupied by these undifferentiated Mesozoic rocks strongly suggests that beds of more than one geologic system are present and that Jurassic rocks may well be included.

On the west coast of Cook Inlet in the Kamishak and Chinitna districts the lowest member of what is now considered part of the Jurassic system, though it may be in part of Triassic age, consists of 1,000 feet or more of porphyry, tuff, and basaltic and andesitic lavas. The relation of these igneous rocks to the overlying sedimentary beds was not determinable through direct observation at the place where they were examined, because the two groups are separated by a fault of great displacement. In the Chinitna district the oldest of the overlying Jurassic rocks have been designated the Tuxedni sandstone (pl. 9, *A*). This formation consists in its lower part of sandstone and sandy shale but includes also conglomerate, grit, arkose, and in the type locality some limestone beds. In the upper part of this formation the rocks are, as a rule, finer-grained, conglomerates and grits become less abundant, and sandy shale makes up a greater proportion of the section. The base of the formation has not been recognized, because part of it has been cut out by faulting. The top of the Tuxedni formation has been determined on paleontologic grounds, as no lithologic break between it and the overlying formation has been recognized. The total known thickness of the Tuxedni sandstone is not less than 7,000 feet, though in different parts of the area it shows considerable variation. The formation is usually abundantly fossiliferous at many different horizons, so that it has been possible for paleontologists to determine its age with considerable certainty. Both plant and animal remains are represented in the collections of fossils from these beds, and from these collections the Middle Jurassic age of this formation has been established. The Tuxedni formation in the Chinitna district is of considerable economic significance, because several of the oil seeps in that district occur in areas where that formation is the bedrock.

Overlying the Tuxedni sandstone, and grading upward from it without recognizable structural break is the Chinitna shale. This formation consists of gray-black and reddish argillaceous shale in which are some sandy and calcareous beds and rarely grit. In the Chinitna district the shale has a rather uniform monoclinal dip eastward and, though here and there dislocated by faults, is relatively little deformed. In the type area, on the north side of Chinitna Bay, the formation was found to be 2,085 feet thick, but considerable departures from this measurement were observed at other places in the same district. One of the most typical and diagnostic fossils found in the Chinitna shale is the ammonite *Cadoceras*. This has a wide distribution, and the shales in which it is found are often referred to as the *Cadoceras* beds. The horizon of the Chinitna shale is determined as being in the lower part of the Upper Jurassic series.

Overlying the Chinitna shale in this region is the Naknek formation, comprising three distinct lithologic members, which from the base upward consist of (1) conglomerate, (2) shales and arkosic sandstone, and (3) light-colored cliff-forming arkosic sandstone, arkose, and tuff. The lowest of these members is called the Chisik conglomerate and is made up of cobbles and boulders of granite or diorite and a variety of other intrusive igneous rocks in a matrix of andesitic tuff. It appears to be entirely conformable with the underlying Chinitna shale, as well as with the overlying member of the Naknek formation. This conglomerate member is about 300 feet thick. No fossils have been found in it, and its age has been determined by its stratigraphic relations to the beds in other formations that contain diagnostic fossils. On this basis it is placed in the lower part of the Upper Jurassic series.

The intermediate member of the Naknek formation, which overlies the Chisik conglomerate, consists at its base of arkosic material, derived in the main from an old land mass from which a great abundance of waste from exposed granitic bedrock was swept into the nearby seas and spread out to form these beds. These coarse arkosic sediments are followed by finer-grained beds composed largely of sandy shales and sandstones.

The uppermost member of the Naknek formation is conspicuous in the landscape, because the beds are more resistant to erosion than the others and therefore form prominent white cliffs on the slopes opposite to those formed by the dip of this formation. The beds are massive and consist of hard arkosic sandstone, andesitic tuff, coarse and fine sandstone, shale, and conglomerate. No fossils have been found in this upper member of the Naknek formation, but the relation of these beds to those of the middle member, in which a characteristic Upper Jurassic fauna has been found, gives ample reason for the inclusion of all these members of the Naknek formation in that series.

The thickness of the Naknek formation is extremely variable in different parts of the field. A composite section that may be considered fairly representative of the formation as a whole in this region would assign the following thicknesses to the different members: Chisik conglomerate member 150 feet or more; shale-sandstone member, 1,500 feet; upper cliff member, 3,000 feet or more.

The Jurassic rocks of the Matanuska and Talkeetna districts embrace a wide variety of lithologic facies and a considerable range in age. The lowermost division, which has been named "Talkeetna formation", is about 3,000 feet thick and consists of lava, breccia, and tuff, interbedded with lesser thicknesses of sandstone and shale. These rocks appear to be closely similar to those in the lower part of the Jurassic section near Seldovia, in Kenai Peninsula. They contain both plant and animal remains that are identified as characteristic of the Lower Jurassic series. Apparently practically all these rocks, pyroclastic as well as sedimentary, were deposited in marine waters, the beds that contain plant fragments marking only temporary intervals when the tracts in which they are found were land areas. The determination of the structure of this formation is complicated by the faulting it has undergone and by the absence of readily identifiable beds that can be traced for long distances. Overlying these pyroclastic and associated rocks in the eastern part of the Matanuska district is a thick series of sandstone with some sandy shale and subordinate amounts of conglomerate. These beds contain abundant marine fossils and some poorly preserved remains of plants. The fossils are closely comparable with those found in the characteristic Tuxedni sandstone, and, although the formation is somewhat thinner than at the type locality, the beds at the two places are correlated and the same name is applied to both. Above the Tuxedni sandstone in the eastern part of the Matanuska Valley is a thick series of shales with lesser amounts of sandstone and conglomerate. The character, stratigraphic relations, and fossil content of this member are so closely analogous to those of the typical Chinitna shale on the western coast of Cook Inlet that the two sections are considered to represent the same Upper Jurassic formation, and the name "Chinitna" is applied to both.

The uppermost formation of the Jurassic system in the Matanuska district is correlated directly with the Naknek formation of the Chinitna district and called by the same name. It consists of green sandy shale several hundred feet thick, which in some places, rests unconformably on the shale and sandstone of the Chinitna shale and in others is overlain unconformably by Upper Cretaceous rocks. A large part of the formation has apparently been removed by erosion. The unconformities at the top and bottom of these Naknek beds, however, are not everywhere recognizable. In fact, at the headwaters of the Nelchina River neither of these unconformities seems to be present, and the Naknek formation grades insensibly downward into the Chinitna shale and upward into Lower Cretaceous beds. Owing to the erosion this formation has undergone, as well as to possible differences in thickness as it was originally deposited, no statement as to its thickness is generally applicable, but apparently as originally laid down it contained several thousand feet of beds.

In the Skwentna and Yentna districts of the Cook Inlet-Susitna region and extending westward into the Kuskokwim region are rocks that are represented on the map (pl. 1) as undifferentiated Mesozoic sedimentary rocks but that include beds which belong to the Jurassic system. One of the oldest of these assemblages was originally called the Skwentna "series" and correlated with the rocks near Naknek. Lithologically the rocks are ancient and somewhat altered volcanics, interstratified with tuffs. In addition to these principal components, some beds of carbonaceous chert and arkose were noted. The thickness of this "series" was not determined accurately but may be 4,000 feet or more. No fossils have yet been found in any of its beds, so that their assignment to the Lower Jurassic rests on general stratigraphic relations to rocks of known age and on their lithologic similarity to the basal division of the Jurassic system in the Seldovia and Matanuska districts.

Toward the heads of the Skwentna and Yentna Rivers is a broad belt of country occupied by rocks that were formerly called the Tordrillo series but are now known as the Tordrillo formation. The lower third of this assemblage of beds consists of massive grit and sandstone, with some conglomerate and argillitic slate. The upper two-thirds is made up principally of argillite with some sandstone and a few beds of limestone. In the Skwentna Valley these rocks overlie those of the Skwentna group, but on the western flanks of the Alaska Range there is a strong unconformity between them and the underlying rocks, which are believed to be Devonian or older. A few small collections of fossils from these rocks have been identified as characteristic of a Middle Jurassic fauna equivalent in part to that of the Tuxedni sandstone of the more southern parts of the Cook Inlet region. The thickness of this assemblage of rocks is estimated to be between 2,000 and 3,000 feet.

Still farther north in the Cook Inlet-Susitna region, especially in the Chulitna and Valdez Creek districts, are Mesozoic rocks that have been shown on the map (pl. 1) as undifferentiated but that may be in part of Jurassic age. The known facts regarding these possibly Jurassic rocks are still so indefinite that it is hardly worth while here to do more than point out the likelihood that more intensive studies may yield positive evidence of such rocks in that region.

Among the places in these districts where the presence of Jurassic and related rocks has long been suggested are the vicinity of the Roosevelt Lakes and the vicinity of Broad Pass. As early as 1898 Eldridge pointed out the similarity of the rocks he called the Susitna slates to those of the Tordrillo Mountains, and Capps later described rocks on the southern slopes of the Alaska Range, from Windy Creek to and beyond the West Fork of the Chulitna, as Jurassic or Cretaceous. These rocks are dominantly mudstone that has become indurated and metamorphosed into shale, argillite, and slate, but they include also a little chert, some conglomerate, and lenses of dark-gray to black limestone. The beds have been unable to withstand the severe deformational stresses to which they have been subjected and consequently are crumpled, faulted, and mashed into a confused complex whose dominant trend is east-northeast and which dips northwestward. No marked stratigraphic break occurs between this unit and either the underlying Triassic rocks or the overlying Cretaceous or younger rocks, so that the lines of separation have been drawn on lithologic grounds, and separation between the possibly Jurassic rocks and those in the lower part of the Cretaceous system has not been attempted. This unit, combining perhaps members of two geologic systems, embraces beds that have a total estimated thickness of 4,000 to 5,000 feet. Only a single fossil has been collected from any of the rocks in this vast area, and that was obtained from rocks presumed to be about midway in the sequence. This fossil was identified only in most general terms—"not older than Upper Jurassic and not younger than Lower Cretaceous."

In the vicinity of the Roosevelt Lakes a conglomerate that appears to overlie the Triassic beds and was originally considered by Moffit to be Triassic or younger is according to Martin possibly part of the Jurassic sequence. Martin further states that this conglomerate strongly suggests equivalence with the Chisik conglomerate of the Chinitna district. This member is at least 400 feet thick and may be as much as 1,000 feet thick, but its contacts with the overlying and underlying formations were not examined in enough detail to determine their relations.

SOUTHWESTERN ALASKA

Rocks of Jurassic age are well known and have widespread areal extent along the coasts of the Pacific Ocean in the Katmai, Kanatak, and Chignik districts and of the Bering Sea in the Naknek, Becharof, and Ugashik districts. Rocks that are perhaps to be correlated with those of the Jurassic system have been recognized at more inland points, especially in the Iliamna, Clark, Mulchatna, and Telaquana districts. In these inland areas the identification of the Jurassic rocks is not only less definite, but the rocks that may belong to that system have not been studied in as much detail as elsewhere, and it has been impossible to map them independently of other Mesozoic beds. As a consequence it has been necessary to group them together as part of the undifferentiated Mesozoic sedimentary rocks.

The Jurassic rocks of the districts along the Pacific coast of the Alaska Peninsula are more or less the direct prolongation of the formations in the districts on the west coast of Cook Inlet, to the north, above described, though showing many local variations of lithology, structure, and thickness. A general section of these rocks for the entire Alaska Peninsula would be closely comparable with the following section, which was determined by Capps in the Cold Bay area of the Kanatak district:

	Feet
Upper Jurassic:	
Naknek formation	5,000+
Shelikof formation	5,000–7,000
Unconformity.	
Middle(?) Jurassic:	
Kialagvik formation	500+
Lower Jurassic:	
Sandstone, shales, etc	2,300±

The Lower Jurassic beds grade downward with no recognizable structural break into the Upper Triassic rocks, the distinction between the two being made purely on paleontologic grounds. In the Cold Bay area the lower half of this unit consists prevailingly of limestone and limy sandstone, whereas in most other areas the limestone is absent or only sparingly represented. The beds carry fairly abundant fossils, but they are mostly forms that are not known elsewhere, so that they do not allow close dating of the beds in which they are found, though apparently belonging in the Jurassic system. Martin suggests that this division may include offshore representatives of the Lower Jurassic volcanic beds of Cook Inlet, though the possibility must not be overlooked that they may represent the highest Triassic rocks, which elsewhere in Alaska either were never deposited or have been removed by erosion.

The Kialagvik formation, so named from its type locality on Kialagvik or Wide Bay, consists of sandstone, sandy shale, and conglomerate. The section at this place is poorly exposed, as the outcrops are interrupted by long stretches in which the bedrock is concealed. The beds are abundantly fossiliferous, however, and the fauna represented is now correlated with those from the Middle(?) Jurassic, though formerly they were considered to be of Lower Jurassic age. Apparently a well-marked angular unconformity separates this formation from the overlying beds. The total exposed thickness of the Kialagvik formation in the type locality is about 500 feet. The Tuxedni sandstone, of Middle Jurassic age, which is about 8,000 feet thick farther north in the Cook Inlet district, has not been directly recognized in the Alaska Peninsula districts, though in part it may be represented by the much thinner Kialagvik formation, or, as Martin suggests, it may be present in small areas that have been overlooked during the hasty reconnaissance surveys.

In the Cook Inlet region the rocks immediately overlying the Middle Jurassic sedimentary beds are called the Chinitna shale. In the Alaska Peninsula area these beds appear to be represented in part of the Shelikof formation, but exact correlation between the two has not yet been definitely determined. According to Capps, the lowest part of the Shelikof formation includes about 1,500 feet of shale. This shale is overlain by 4,000 to 4,700 feet of sandstone and sandy calcareous shale, in which fossils comparable with those from the Chinitna shale are common. The uppermost member, which is from 700 to 1,000 feet thick, is composed of black shale, with some limestone lenses and nodules. In places this shale is sandy and calcareous, but usually it is rather barren of fossils. The few fossils that have been found in this upper shale member are not characteristic of special horizons in the Jurassic.

The uppermost formation of the Jurassic sequence in the Alaska Peninsula region is the Naknek. This formation here retains most of the characteristics that it shows in the Cook Inlet region. It is composed of beds of arkose, conglomerate, sandstone, and shale having a total thickness of many thousand feet. The thickness varies greatly, however, in different parts of the area, as would be expected in a formation made up so largely of coarse detritus. These beds are abundantly fossiliferous, and usually the fauna is sufficiently distinctive to warrant assignment with little hesitation to the upper part of the Upper Jurassic series.

The type locality of the Naknek formation (originally called Naknek series) is in the vicinity of Naknek Lake. The exposures in this place were described by Spurr as in part composed of greenish volcanic rock and in part of horizontal sedimentary rocks, which formed the bulk of the country nearly as far east as the pass to the Katmai River. Near the pass the sequence is interrupted by Tertiary and Recent volcanic rocks, but farther east, down the Katmai River, the same assemblage of rocks again crops out and extends all the way to Katmai Point.

The most southwesterly point in the Alaska Peninsula at which Jurassic rocks have been definitely recorded is in the Herendeen Bay area, where there are several small outcrops. These beds evidently are part of the Naknek formation, but the lowermost beds of that formation are not exposed, and the relation between them and the overlying rocks is not such as to permit determination whether or not the two are conformable. Fossils are fairly abundant in most of the beds and are characteristic of the Upper Jurassic fauna.

Rocks that possibly are of Jurassic age but that have not been separately distinguished on the geologic map, plate 1, and have been included in the group of undifferentiated Mesozoic sedimentary rocks occur along the western flanks of the Alaska Range in the Telaquana, Clark, and Mulchatna districts. These beds are evidently the southwestern extension of some of those of the Skwentna and Tordrillo formations in the Cook Inlet region, described above because volcanic flows and tuffs comparable with the Skwentna group and sedimentary rocks comparable with those of the Tordrillo formation occupy extensive areas in these districts. Exact correlation of these rocks, however, is not yet possible, because of the lack of precise information, and it is now well known that beds of systems other than the Jurassic are included in the great thickness of Mesozoic rocks represented. In describing a cross section from a locality near the base of the exposed Mesozoic rocks in the Kuskokwim region, in the vicinity of the Stony River, southeastward to the top of the rocks that were considered of Mesozoic age, the writer recognized three rather distinct lithologic types—namely, a basal member of rather massive conglomerate, an intermediate member composed dominantly of shale but containing some sandstone, and a top member composed dominantly of sandstone with subordinate shale. On the basis of the field evidence, the writer concluded that some of these rocks were probably Jurassic or younger, and Capps, who studied the more shaly and graywacke phases near the mountain flanks, concurred in this general age determination for the rocks in his area. Martin, however, on theoretical grounds was inclined to regard all the Mesozoic rocks described by the writer as Cretaceous. The determination of the true age of these rocks must evidently await further field studies and more critical investigations. On Kodiak Island slates and graywackes in complex relations with other sedimentary, intrusive, and bedded volcanic rocks have been correlated at different times with various parts of the stratigraphic column. Certain deposits near Kodiak have afforded fossils which Ulrich identified as Lower Jurassic, but this determination is open to doubt, and the fauna may be Cretaceous. The areal distribution of the beds in which they occur has not been mapped separately, and these rocks, as well as the others that may belong to other systems, have been shown as undifferentiated Mesozoic sedimentary rocks on the accompanying map.

NORTHERN ALASKA

In northern Alaska the only place where Jurassic rocks that are definitely identified occupy a sufficient area to be shown on plate 1 is in the central part of the Canning district, but rocks of that system have afforded diagnostic fossils from exposures in the Firth River Valley, in the extreme eastern part of the same district. Rocks that were formerly regarded as of Jurassic age but are now assigned to the Cretaceous crop out in the Lisburne district. The two more eastern of these localities are of special geologic significance because, so far as known, they are the only occurrences of marine Jurassic beds in the entire region north of the Alaska Range.

The known Jurassic rocks in the central part of the Canning district are exposed in the valleys of the Canning and Sadlerochit Rivers and have been called the Kingak shale. This formation consists of about 4,000 feet of black shale, which overlies the Shublik formation of the Triassic and underlies the Ignek formation, which is regarded as probably Jurassic. Fossils are common only in the rocks that are about 1,500 feet above the base of the Kingak shale. Identification of the fossils collected has led Stanton to correlate the beds with the Middle Jurassic series. Even if this identification is correct for the fossils collected, however, it by no means follows that the whole section is Middle Jurassic, for there are nearly 1,500 feet of beds below the fossil horizon and 2,500 feet above it that might, if carefully searched, be found to contain fossils characteristic of other parts of the Jurassic column.

In this same general neighborhood, in the valleys of the Canning River and Marsh Creek, is an assemblage of rocks that Leffingwell called the "Ignek formation." This consists of about 2,500 feet of black shale with burnt coal beds, which have given a strong red color to the nearby shales and subordinate amounts of sandstone. Although apparently the Ignek formation overlies the Kingak shale, this inference is somewhat open to doubt, as the true relation may have been obscured by faulting. The uppermost beds of the Ignek have apparently been removed by erosion, and the relation of the highest beds that have been preserved to the younger rocks has not been determined. The fossils collected from this formation are extremely puzzling, so that, on the basis of the data now available, it is impossible to determine the age of these beds more closely than Jurassic or Cretaceous. They are tentatively classified as Jurassic(?).

The locality of known Jurassic rocks in the eastern part of the Canning district was discovered by Maddren and is in the valley of the Firth River about 8 miles west of the international boundary. The Jurassic rocks there, however, are so intimately associated with beds of Triassic age that little more is known about them than that they seem to consist of a thin ferruginous bed in the midst of Upper Triassic shales and limestones. The fossils contained in this ferruginous bed consist wholly of crinoids, and their correlation with other fossils is extremely obscure, but Springer stated that the crinoids suggested Lower Jurassic age and were probably of the same species as those obtained from rocks in the Canning River locality, which, however, were more abundantly fossiliferous and were regarded by Stanton as Middle Jurassic.

In the Lisburne district, in the extreme western part of northern Alaska, rocks of the Corwin formation have long been tentatively regarded as Jurassic, and even now certain paleobotanists are not entirely convinced that the fossil flora that is found in the beds does not belong to that system. However, these supposed Jurassic rocks have been traced almost continuously along the strike into rocks containing both plant and animal remains that are identified as Cretaceous. Under certain circumstances this discrepancy might be reconciled by considering that the formation was a unit containing members of both systems and thus of Jurassic and Cretaceous age. This simple solution of the difficulty does not appear permissible because in the same region there are definitely recognized Lower Cretaceous rocks, and elsewhere than in the Corwin area the beds in question lie above the Lower Cretaceous beds, so that there would be an almost impossible stratigraphic relation if these beds were really Jurassic. Though admitting that the question cannot be finally settled from the facts available, the writer has felt that the only practicable solution of the problem for the present is to refer these rocks to the system which the bulk of evidence now favors. For that reason these beds are now regarded as of Cretaceous and not Jurassic age. More reluctance to adopt this course would be felt if it were not known that, as a rule, floras are less quickly responsive to geologic changes than faunas, and that the supposed Jurassic flora of the Corwin formation does not show a close relationship to any of the undoubted Jurassic floras of southern Alaska.

Owing to the exploratory methods employed in the surveys of much of northern Alaska, it has obviously been impossible to examine in detail the geologic formations exposed, so that it is by no means certain that the lack of recognition of Jurassic beds elsewhere in that vast area should be interpreted as proving that such rocks do not occur there. The fact that none have been recognized seems significant, however, and it now seems likely that during the Jurassic period all of Alaska north of the Alaska Range was land area, outside the influence of the Pacific Ocean of that time, and that the Jurassic beds in the extreme northeastern part of the Territory mark a minor incursion of non-Pacific marine waters from the north and east. Such an explanation would fit in well with the known major mountain building and batholithic intrusion that appears to have begun in the Jurassic and to have blocked out many of the main orographic features of Alaska, the relics of which are still recognizable.

OTHER REGIONS

As noted elsewhere, rocks that in part at least are correlated with some of the members of the Jurassic system extend from the Cook Inlet-Susitna region and southwestern Alaska into contiguous parts of the Kuskokwim region, but no additional information about them there is available. Undifferentiated Mesozoic rocks that may possibly include Jurassic beds but are more likely to be younger were recognized by Maddren in the highlands that form the watershed between the Kiselalik and Aniak Rivers, which are tributaries from the south to the Kuskokwim River in the Akiak district.

Extending from the Cook Inlet-Susitna region into adjacent parts of the Alaska Gulf region is a complex assemblage of slates, graywackes, and related rocks, which in different areas have been called by different names, as for instance, the †Sunrise, the Valdez, the Orca, and the Yakutat groups, and, by B. K. Emerson, the Vancouver "series." These different units have some features in common and some striking differences, which lead to the conclusion that several different divisions are included in this assemblage and that as yet no close correlation of the different divisions is warranted. This complex assemblage has been represented on the accompanying map (pl. 1) as undifferentiated Mesozoic sedimentary rocks, though it has by no means been proved that as thus mapped some Paleozoic beds may not have been erroneously included, because their true age has not been recognized. Some of the rocks in this great assemblage contain fossils suggestive of the Jurassic, but this evidence is not conclusive, and even if true it would not be adequate to permit the delimitation on the geologic map of the areas occupied by the rocks of that age, for equally strong fossil evidence suggests that other beds are Cretaceous. Undoubtedly, in this very thick section there is considerable reduplication of beds through isoclinal folding and faulting, but the absence of recognizable key beds has prevented the unraveling of their structure.

CRETACEOUS SYSTEM

The events marking the passage from the Jurassic into the Cretaceous period are not well recorded in the Alaskan areas that have been studied in most detail, so that it is now impossible to reconstruct the history of that time with any degree of confidence. According to Martin the land mass of Alaska was worn down to a low relief by the end of the Jurassic period, and the seas of that time were largely filled with sediments. In the early part of the Cretaceous period the sinking of part of the land led to incursions of the sea, followed by oscillations of greater or less amounts at various times during the Cretaceous, so that in the course of that period practically all of Alaska was at some time under the sea, though at no one time were all parts of it submerged coincidently.

Marked changes in the life of the area occurred. Plants were much more abundantly preserved in the Cretaceous deposits than in those of the older systems, and the dicotyledons became significant members of the flora. Diastrophism and the injection of igneous masses, which seem to have begun in the Jurassic, were continued into the Cretaceous, and new expressions of these processes were initiated at other places during this period. It was a time of varied geologic activities, and the record of these activities is, on the whole, much more completely preserved in the deposits of this system than that of similar events in the older systems, though these records have by no means been deciphered with the degree of thoroughness that they merit.

Martin has summarized his interpretation of the broader aspects of Cretaceous geology. An outline of his views comprises widespread transgression of the Lower Cretaceous seas over Alaska, followed by lesser transgression of the Upper Cretaceous seas, which did not extend far into the axes of the present mountains, because those areas had already been outlined by uplifts during the period.

SOUTHEASTERN ALASKA

In southeastern Alaska no specific basis for the differentiation of the Jurassic and Cretaceous deposits over wide areas has yet been discovered, and although beds that are believed to be of Lower Cretaceous age have been mapped in that region, the correlation is uncertain and subject to emendation as further information is obtained in the course of field studies. As at present recognized the uppermost part of the Jurassic section of layered rocks is composed dominantly of lava flows and volcanic products, such as tuff and breccia. The line of separation of this system from the overlying one is drawn so that these volcanic rocks are segregated from the sedimentary beds above that are almost free from any considerable amount of volcanic material. This plane of separation also marks the parting between two systems of rocks that apparently show different degrees of metamorphism and contain two different types of *Aucella* fossils. According to Martin, the junction between the two types of deposits marks a pronounced unconformity, but Buddington, who was especially familiar with the field relations of the two, did not recognize that break.

Rocks that are now considered to be Cretaceous are known at five principal localities in southeastern Alaska—namely, near Pybus Bay and in adjacent areas in the southern part of Admiralty Island; on the peninsula between Hamilton Bay and Keku Straits, on the northwest coast of Kupreanof Island; on the southern and western coast of Etolin Island; at Blank Inlet, Gravina Island; and at Slocum Arm, Chichagof Island. At all these places the supposed Cretaceous beds are composed dominantly of black slate or shale and graywacke, with usually some beds of conglomerate and calcareous sandstone and thin layers of impure limestone. The fossils that have been collected from these rocks have in the main been identified as probably Lower Cretaceous, although in several instances this identification has been restricted by the addition of the qualification "or Jurassic." Apparently these Cretaceous rocks, in every place where their relations to younger sediments can be observed, lie unconformably below the later rocks. So far as reported, no sedimentary rocks that were formed in Upper Cretaceous time have been recognized in the entire region, and probably they are not present. This would strongly point to the conclusion that during that epoch the country was being uplifted through batholithic intrusions and related processes, so that for most of that time the region was a land area not receiving deposits of sediments. If this is so, it would be in striking contrast to the conditions that prevailed throughout most of the other parts of the Territory.

COPPER RIVER REGION

Rocks of Cretaceous age have been recognized in the Copper River region mainly in the central part of the Chitina Valley, especially in the valleys of the tributary streams that come in from the north. In addition to the beds that are certainly Cretaceous there are others that are doubtfully referred to that system or the Jurassic. To the latter class belong some of the rocks in the Kotsina-Kuskulana district. There the rocks in question occur in small discontinuous exposures and show a wide range in lithology. Such fossils as have been collected from these rocks are rather unusual forms, or their range is not known, and they are not sufficiently numerous and diagnostic to permit close identification of the system to which they belong. In view of the conflicting evidence so far obtained, it seems likely that representatives of both systems are present rather than that the beds are either all Jurassic or all Cretaceous. The present discontinuity of the exposures appears to be due to removal of parts by erosion rather than to original deposition as isolated patches. This assemblage of beds has been long known as the Kotsina conglomerate. It is dominantly a dark conglomerate without prominent bedding planes, associated with small amounts of black shale. The Kotsina formation rests with marked unconformity on underlying rocks which differ greatly in age in different parts of the district. Owing to the erosion to which these beds have been subjected, their total thickness shows great variation in different sections.

The beds that make up most of the Cretaceous deposits of the Chitina Valley are chiefly black shale and sandstone, with subordinate amounts of conglomerate, grit, and gray sandy shale. These rocks are all less deformed by folding and faulting than the older rocks that lie stratigraphically beneath them, although the black shale is locally much folded and compressed. In the past the Cretaceous rocks of the Chitina Valley area have been described as belonging in part to the Lower Cretaceous and in part to the Upper Cretaceous epoch. Later investigations, supplemented by more extensive collections of fossils, have brought that division into serious question, and it now seems likely that no Upper Cretaceous sedimentary rocks occur in the district.

The Cretaceous sequence of Fourth of July Pass consists of a few feet of conglomerate overlain by a few hundred feet of sandstone, which is in turn overlain by shales more than 3,000 feet thick. The lower part of this sequence yielded the fossils on which the original age determination of the Kennicott "series" was made. Slightly later the Kennicott formation was extended to include all the rocks that were thought to be of the same age as those of Fourth of July Pass. However, at that time the age of the assemblage was considered to be Jurassic. Still later the term was redefined by Martin, who, as a result of his studies, had reached the conclusion that the beds were probably Lower Cretaceous and proposed to restrict the name "Kennicott" to the lower conglomeratic and sandstone beds. Although this definition may prove useful later, when more detailed stratigraphic work has been done, Moffit does not adopt the term "Kennicott formation" in the latest report on the region, but instead refers to the rocks that are in whole or in part the equivalent of that formation simply as "Lower Cretaceous rocks", in accordance with the present opinion of the paleontologist concerning their age. All these Cretaceous rocks appear to have been intruded by large masses of granite and quartz diorite and are cut by dikes and sills of light-colored porphyritic rocks.

The fossils collected from this sequence of Cretaceous rocks include both plants and marine animals. A review of all the invertebrate collections has led Reeside to conclude that the fossils so far obtained appear to have closer affinities with Lower Cretaceous forms than with those of any other epoch. The identification of the plants, however, led Knowlton to the opinion that they represented a Jurassic rather than a Cretaceous flora. These two conflicting views cannot be finally reconciled until additional data are obtained, but in view of the present necessity of making a tentative decision between the two, it has seemed more likely that the correct assignment is to the Cretaceous. In reaching this decision, weight was given to the well-known fact that in general after a change there is a greater lag in response by a flora than by a fauna, that the invertebrate collections are much more numerous than the plant collections, and that certain of the invertebrate forms, the ammonites, have had their vertical range pretty definitely established.

Rocks that may be in part of Cretaceous age occupy much of the region south of the Chitina River from the head of the Bremner River westward. They consist of alternating bands of dark slate and graywacke, with subordinate amounts of conglomerate and grit. In the Klutina district, west of the Copper River, the sequence is continued. Here the rocks are dominantly slate and graywacke, seamed with numerous quartz veins and associated with small and inconspicuous beds of conglomerate and grit. Locally these beds have been altered through dynamic processes, so that in places they have become somewhat schistose. None of these rocks have been mapped separately on plate 1 but all have been grouped together as part of the undifferentiated Mesozoic sedimentary rocks. These supposed Cretaceous rocks are part of the sequences that in the past have been given various designations, such as the Valdez "series" (now group), which has in turn been correlated with the now discarded Sunrise "series." Undoubtedly rocks having a considerable range in age have thus been grouped together, but certainly part of the old †Sunrise "series" is now known to be made up of rocks that contain distinctive Cretaceous fossils. It should be noted, however, that the fossils that have been found in these less well identified Cretaceous rocks appear to have Upper Cretaceous affinities and thus may mark a much higher stratigraphic position than the definitely identified Cretaceous rocks, all of which are referred to the Lower Cretaceous.

COOK INLET-SUSITNA REGION

In the Cook Inlet-Susitna region the only place where Cretaceous rocks have been definitely recognized in areas large enough to be shown on the accompanying map is in the Matanuska district. At several other places rocks that are, in part at least, of Cretaceous age have been found, but their relation to other rocks or their small extent has made it impossible to map their distribution from the facts now in hand and these occurrences have been included in the areas occupied by the undifferentiated Mesozoic sedimentary rocks. Among the areas of this sort may be mentioned the Anchorage district, Kenai Peninsula east of Cook Inlet, and the Yentna and Skwentna districts west of the inlet.

In the Matanuska district the lowermost Cretaceous sedimentary beds seem to be conformable with the underlying Jurassic rocks. At its base the Cretaceous section consists of conglomeratic tuff and arkose about 200 feet thick, overlain by several hundred feet of a massive dark fine-grained limestone. Originally these rocks were included in the so-called Matanuska "series", but this name was later restricted in the term "Matanuska formation", to the higher beds of the Cretaceous system, and no specific name was given to the conglomerate and tuff beds, though the name "Nelchina limestone" was applied to the limestone unit. These Cretaceous beds, up to and including the Nelchina limestone, have been assigned, from the few fossils they contain, to the Lower Cretaceous epoch, though this fossil evidence is by no means incontrovertible. Apparently they are separated from the overlying beds by an unconformity of unknown magnitude.

The higher beds in their lower part are dominantly shale with subordinate amounts of sandstone and are about 2,000 feet thick. They merge upward into beds consisting predominantly of sandstone with relatively thin shale layers at intervals. The sandstone unit is composed of beds having a total thickness of 2,100 feet. These two units have been included under the single name, "Matanuska formation", by a redefinition of the former Matanuska "series", which included these as well as the Lower Cretaceous and some Jurassic rocks. The fossils found in the shale members of the Matanuska formation are all marine forms and are distinctly Upper Cretaceous species. In the sandstone members some plant remains have been collected in the uppermost beds, whose relations to the overlying Tertiary rocks is by no means definitely established These fossil plants differ in their aspects from the more characteristic Tertiary or Mesozoic floras, and the age of the beds in which they occur is therefore subject to some uncertainty, though Martin believes that in lithology they are more analogous to the Cretaceous beds than to the Tertiary rocks, in that they are somewhat more indurated and seem to have been involved in intense deformation to which the Tertiary beds were not subjected. In general, the youngest of the recognized Upper Cretaceous beds is separated from the overlying Tertiary rocks by a strongly marked unconformity.

In the Girdwood area of the Anchorage district the bedrock consists of a thick sequence of argillites and graywackes, with minor amounts of conglomerate, limestone, and partly indurated sandstone. These beds have been strongly deformed, tilted, and fractured. Measurements across the general trend of these rocks indicate that several miles of strata are included, but doubtless this great thickness is apparent only, being due to undetected duplication. In six different localities within the area adjacent to Girdwood fossils were collected from these rocks, all apparently representing a single species. In reporting on these fossils Reeside stated that, in his opinion, they were Cretaceous and more likely to be Upper Cretaceous than older. The structure is so complex, however, that it is impossible from the evidence in hand to determine positively either that all of the apparently unbroken sequence is in reality a unit or just what is the stratigraphic position of the beds from which the fossils were obtained. For the present, therefore, all that can be said is that some Cretaceous beds certainly occur in the sequence and that such of these beds as are now recognized as Cretaceous are believed to be of Upper Cretaceous age.

The identical assemblage of rocks that here and there in the Girdwood area contains Cretaceous fossils extends both to the northeast into the Prince William Sound region and southward into the Kenai Peninsula. Although in neither of these other areas have diagnostic fossils yet been found, it is with all confidence that at least part of the rocks in these areas are believed to belong to the Cretaceous system. However, the uncertainty as to what that part is makes it necessary to map all those areas in which this complex assemblage occurs as undifferentiated Mesozoic sedimentary rocks. Thus, from the southernmost tip of Kenai Peninsula all the way northeastward into the Copper River region, as already described, are sandstone, graywacke, and shale beds of complex structure and relations that are probably in part of Cretaceous age, though the correlation has not been completely demonstrated, and the distribution of the comparable individual members has not been determined with precision.

In the areas west of Cook Inlet the assemblage that is believed to embrace in part Cretaceous sedimentary rocks comprises mainly black and gray slates, phyllites, and graywacke. These beds have been examined in most detail in the Yentna district, especially in the vicinity of Cache Creek and in the valley of the Tokichitna River. They have been strongly deformed and are much jointed. The section embraces several thousand feet of beds, even if it has undergone considerable duplication through faulting. Only a few fossils have been collected from any of these beds, but a small lot from Long Creek, a tributary of the Tokichitna River, contains specimens of marine animals which Stanton considers more like those from Upper Cretaceous beds than from any other series, though he states that other collections are necessary before that identification can be considered positive.

Southwestward from the Yentna district the same general assemblage of rocks extends through parts of the Skwentna and adjacent districts of the Cook Inlet region and also into the neighboring districts of the Kuskokwim region and of southwestern Alaska. In all these areas there is a great sequence of beds consisting dominantly of argillite, shale, sandstone, and graywacke, practically devoid of fossils and lacking readily recognizable key horizons of reference. Some of these rocks undoubtedly belong to different systems, but it is equally certain that some of the beds are Cretaceous. For instance, a single specimen of a marine invertebrate collected from a member of this assemblage of rocks in the headward part of the Stony River Valley of the Kuskokwim region was identified by Stanton as Cretaceous and probably Upper Cretaceous. Another specimen from the Mulchatna Valley was determined as either Jurassic or Cretaceous, and a leaf imprint from rocks in the Skwentna Basin was determined by Hollick as either Cretaceous or Tertiary. These are the only collections yet obtained from this group of rocks, and obviously the information they furnish is insufficient to serve as a basis for a definite conclusion. The facts available, however, are adequate to warrant the statement that some of the rocks, perhaps a large part of this assemblage, are Cretaceous. Certainly so far as now known this group appears to lie unquestionably above the known Triassic rocks and to underlie unconformably the recognized Tertiary beds of early Eocene age.

SOUTHWESTERN ALASKA

The extension of formations that are in part at least of Cretaceous age from the Cook Inlet region on the north into southwestern Alaska has already been discussed in general terms in the preceding portion of this report. In addition to these indefinitely determined members of this system there are a number of localities where unquestionable Cretaceous rocks have been found, and several of these are appropriately indicated on the accompanying map (pl. 1). In fact, according to Martin, the Alaska Peninsula affords one of the most complete sections in Alaska of the Cretaceous system that has been studied with a fair degree of thoroughness, though the thickness of the beds there appears to be much less than in other districts.

The general succession of Cretaceous rocks in this region appears to comprise the Staniukovich shale at the base, overlain by the Herendeen limestone, overlain in turn by the three members of the Chignik formation. The Staniukovich shale, where examined, is dominantly composed of thin-bedded shale with subordinate amounts of sandstone and still less conglomerate, resting apparently unconformably on Upper Jurassic beds. Its total thickness is estimated as in excess of 1,000 feet. The fossils from this formation are marine organisms and are regarded as indicating a Lower Cretaceous fauna. Overlying the Staniukovich shale with evident conformity is the Herendeen limestone, whose thickness in the type locality, at Herendeen Bay, in the Moller district, is about 800 feet. This formation is in the main composed of light-gray arenaceous cross-bedded limestone, which, because of its greater resistance to erosion than the adjacent shales, usually stands up as conspicuous ridges in the landscape.

Although considerably folded and deformed, the limestone is by no means badly disorganized by the mountain-building processes to which it has been subjected, and its general structure is readily determinable. Numerous whole shells of extinct marine forms have been collected from these beds, and comminuted fragments of apparently similar types are extremely abundant in certain layers. From these fossils paleontologists have decided that the beds from which they were obtained are Lower Cretaceous and belong well toward the top of that series. A fossil plant that was said to have been obtained from these beds was at one time identified as a Jurassic species. This raised some doubt as to the accuracy of the identification as Cretaceous. However, it now seems likely that the collections became mixed in some fashion so that the fossil plant probably did not come from these beds and may not even have come from this general area. Furthermore, it is possible that the identification of the plant as Jurassic may have been erroneous and that instead it is a closely related Cretaceous species.

Unconformably overlying the Herendeen limestone is a marine shale that forms the lowest of the three members of the Chignik formation. This unit embraces about 200 feet of beds. It is succeeded by a shale with many interlayered beds of coal and some sandstone, the total thickness of which is approximately 300 feet. Still higher in the section and forming the uppermost member of the Chignik formation are conglomerate, sandstone, and shale that contain marine forms as well as fossil plants. These beds were evidently deposited under conditions of instability whereby oscillations from marine to land conditions occurred at intervals. The occurrence of coal beds in this formation gives it considerable economic significance, because both at Herendeen Bay and near Chignik the coals have been mined to some extent for local consumption. In fact, coal mining was in progress in the Herendeen Bay region as early as 1880 and in the vicinity of Chignik in 1893, though the amount of coal produced to date has been small. Some of the coal beds have properties that place them close to bituminous in rank, though others are distinctly lignitic. Several of the specimens tested showed a calorific value as received of 10,000 to 11,000 British thermal units, and one from Herendeen Bay ran as much as 11,785 British thermal units. The ash content, however, of most of these coals is high, averaging perhaps 15 percent but running up to 25 percent. The age of these beds has been definitely placed by their floras and faunas as Upper Cretaceous, though more complete collections will be required before close correlation of these beds with other representatives of this epoch elsewhere can be made with certainty.

In the Tikchik district, in the western part of southwestern Alaska, are certain rocks that are assigned with considerable confidence to the Cretaceous and others that are less definitely correlated with members of that system. The more definite Cretaceous rocks occur in the hills near the head of the Nushagak River and probably form much of the country in the divide between that stream and the Holitna River, a tributary of the Kuskokwim. In the main these rocks are sandstones and graywackes, but doubtless associated with them is considerable shale, which, however, is not conspicuous because it is less resistant to weathering and thus may escape notice by a geologist engaged in a rapid reconnaissance of the region. Fossils characteristic of an Upper Cretaceous fauna were found in the area where these strata form the bedrock. Although members of some other series may be associated with these rocks, but not differentiated from them, it is believed that on the whole the section there is dominantly composed of rocks of Upper Cretaceous age.

The less definitely determined Cretaceous rocks lie south of Lake Nuyakuk and consist mainly of dark-colored, rather fine grained graywackes and slates. Owing to their proximity to the zone of mountain building in the highlands west of the lakes and possibly because of their nearness to places where igneous intrusion has occurred, these supposed Cretaceous rocks are somewhat more deformed and lithified than comparable rocks elsewhere. In fact, it is this difference in lithology that raises some doubt as to the correctness of their correlation with the Cretaceous and suggests that possibly they are older. It seems almost certain that they are not the exact equivalent of the Cretaceous rocks in the headwater region of the Nushagak River Basin, and the writer believes that if they really are Cretaceous they are likely to belong in the Lower Cretaceous series. No fossils have been found in them. The absence of fossils does not seem to be due to their having been subsequently destroyed by geologic processes but rather to the fact that life was sparse in the old sea where the sediments were being laid down. This explanation would be in good accord with what has been learned as to the marine life of the Lower Cretaceous sea in western Alaska, for very few organic forms have been found in any of the deposits laid down in those waters.

KUSKOKWIM REGION

The extension of certain of the Cretaceous rocks that have been described as occurring in the Cook Inlet and southwestern Alaska regions into adjacent parts of the Kuskokwim region has already been noted. Such areas fall principally within the eastern and southern parts of the Tonzona and Georgetown districts. In addition to those areas, extensive tracts of definitely known Cretaceous rocks have been mapped within the Kuskokwim Basin, and doubtless the extent of these rocks would be found to be much greater if that basin had been completely mapped. As now known, there is a large area of Cretaceous rocks in the northern part of the Kuskokwim Basin extending northeastward from the vicinity of Akiak to and beyond Medfra that is part of an even more extensive area embracing large parts of the Innoko and Iditarod districts of the Yukon region. In addition there are in the southern and western part of the Kuskokwim Basin rocks that among others of Mesozoic age probably include considerable bodies of Cretaceous sediments, but owing to the present inability to differentiate the supposed Cretaceous rocks from others in these areas, all have been grouped together as undifferentiated Mesozoic sedimentary rocks on the accompanying map (pl. 1). Areas of this sort are now known to occur in the hills forming the divide between the Aniuk and Kiselalik Rivers, in the highlands near Mount Oratia, and in the vicinity of Goodnews Bay.

The Cretaceous section of the northern area appears to have at its base coarse conglomerate which rests unconformably on a basement composed of rocks of many different ages in different parts of the area. The conglomerate is succeeded by a monotonous succession of sandstones and shales with practically no recognizable key beds and embracing a total thickness of thousands of feet. Such recognizable fossils as have been collected from members of this sequence have in the main been marine forms but include fragments of vegetation such as might have been drifting on marine waters near shore and some dicotyledonous leaves that may have been trapped in deposits formed either on land or in the sea. Apparently, the marine sediments were laid down near shore, as they show shallow water and current features, such as cross-bedding, ripple marks, and mud cracks. As a rule, these Cretaceous beds have been openly folded and not closely deformed or greatly broken during the mountain-building movements to which they have been subjected, but this seems to be true only in this area, which was relatively remote from the zones of greatest orogenic stresses. Only a few collections of fossils have been made from these rocks, and although none of them contain specifically identifiable forms all of them have been regarded as indicating Upper Cretaceous affinities. The possible presence of Lower Cretaceous rocks in this northern area is vaguely suggested by outcrops in the valley of Meadow Creek northeast of the Sunshine Mountains, where certain of the fossils collected were identified as "Jurassic or Cretaceous", though the collection as a whole was regarded as most likely Upper Cretaceous. The upper limit of the age of this sequence of rocks is also open to some doubt, because some of the uppermost beds seem to extend into the Tertiary without recognizable stratigraphic interruption.

In the supposed Cretaceous area in the western part of the Kuskokwim Basin the correlation of some of the rocks with this system is decidedly open to question and has been based almost exclusively on lithologic similarity to rocks in areas where the age has been more definitely determined. In spite of this indefiniteness, however, it is believed that the correlation is well justified for some of the rocks, though it is not yet possible to differentiate those to which this interpretation should apply from those of some other age. Martin has called attention to the fact that fossils collected from a float boulder on the Kanektok River in the Bethel district belong to a fauna that he regards as Lower Cretaceous, but this is the only specific reference of rocks to that series that has yet been made in the entire Kuskokwim region, and the fact that the beds from which the boulder came were not seen in place makes this determination of doubtful significance, especially as the bedrock of the country where the boulder was found was described as part of the †Oklune series, an assemblage that is now believed to embrace so wide a variety of units that the term has practically no time significance.

In the Goodnews Bay district the geologic investigations were carried on so hurriedly that it was impossible to differentiate the rock units in other than general terms. As a result the bedrock of a considerable tract of country is described only as Mesozoic (?) sandstones, slates, argillites, cherts, and graywackes, with which are associated numerous igneous flows and tuffs. The general lithology of some of the specimens collected, especially of the sandstones and graywacke, so closely resembles the characteristics of the known

Cretaceous rocks elsewhere in the Kuskokwim Basin that little doubt is felt that some of these rocks will be proved to be Cretaceous when more detailed work is done in the area, though now it is unwarranted to indicate that belief by showing any specific areas in this district on the accompanying geologic map as formed of Cretaceous rocks.

YUKON REGION

The mapped areas of Cretaceous rocks in the Yukon region probably include only a small part of the area that is actually occupied by rocks of this age, because extensive tracts of the region are still entirely unexplored. As mapped (pl. 1), the known areas may be grouped into six more or less definite geographic units which, for simplicity of description, may be designated (1) the Marshall area, embracing the known occurrences along the Yukon River from a point below Andreafski upstream nearly to Holy Cross; (2) the Nulato area, embracing scattered patches of Cretaceous rocks along the Yukon northward from the northern outlet of the Innoko River to a point near Kaltag and thence northward and westward not only along the river but also inland to and beyond the divide between the Yukon and Norton Sound drainage basins; (3) a large tract in the Iditarod and Innoko districts extending into the headwaters of the Nowitna River and merging into the Upper Cretaceous area in the northern part of the Kuskokwim region described above; (4) a tract extending northward from the Yukon near Louden and Ruby, embracing much of the country in the Koyukuk and its tributary valleys almost as far as the settlement of Coldfoot; (5) a tract in the Hot Springs and Rampart districts; and (6) a tract in the vicinity of the Yukon River and the international boundary east of Woodchopper.[23a] Other areas of possible Cretaceous rocks occur in the Yukon region, though they have not been specifically indicated on the geologic map (pl. 1) but are included in the group of undifferentiated Mesozoic sedimentary rocks. Among areas of this sort the most noteworthy is in the Chisana and White River districts, in the Alaska Range adjacent to the international boundary.

In the area near Marshall the most common rock types are sandstone and graywacke, but some conglomerate and argillite occur at intervals through the section. Some of the conglomerate, especially that near Holy Cross, seems to mark a basal member of the sequence, and Martin has suggested its correlation with the Ungalik conglomerate, of Cretaceous age, in the Seward Peninsula region. The lithology of the sequence differs considerably in different parts of the area, probably largely in response to the differences in the bedrock of the old land from which the sediments were derived and in the processes that were active in their transportation and deposition. The fossils collected from these beds represent both marine animals and land plants, so that the beds were evidently laid down under varying conditions and in varying environments. On the whole, however, the marine waters in which they were deposited appear to have been rather shallow, as many of the beds show near-shore aspects and none of them indicate formation in deep water. All the fossils that have been definitely identified are Cretaceous forms, and most of them suggest that they probably came from beds in the upper part of that system.

In the area adjacent to Nulato there is a tremendous display of conglomerate, grit, sandstone, and shale that forms practically all the bedrock in the entire tract between the Yukon River and Norton Sound—an airline distance across the general strike of the formation of about 80 miles. Apparently the assemblage has been deformed into rather open folds, and some duplication of beds has been caused by faulting. On the whole, however, the series forms a single conformable succession of great thickness. The lowermost formation of this series is a massive conglomerate, the Ungalik conglomerate, but this formation has not been recognized in the Yukon Valley near Nulato, though it has been found along the western margin of these beds in the Seward Peninsula and in the area near the Melozitna River north of Ruby in the Yukon Valley. The beds above the basal conglomerate have been described as the Shaktolik group, but later, without much additional field evidence and mainly on theoretical grounds, this group was subdivided by Martin into the Melozi, Nulato, and Kaltag formations, named in ascending order. A significant economic feature of this succession of rocks is the occurrence in it of coal beds that have been mined at several places to supply local needs. Both plant and marine animal remains have been found in these beds, which are now identified as of Upper Cretaceous age, though at first, before as abundant specimens were available for comparison, the beds were considered to be Tertiary. No reliable measurement of the thickness of these beds is available, but from their extent and such partial measurements as have been made it seems likely that this unbroken sequence is at least 10,000 feet thick.

The Cretaceous rocks that have been recognized in the Innoko-Iditarod and adjacent parts of the Yukon region are the prolongation of the Upper Cretaceous rocks in the neighboring districts of the Kuskokwim region. In their lithology, structure, and age the rocks in the two regions present essentially identical

[23a] Since the foregoing was written the discovery and identification by Professor Chaney of Upper Cretaceous fossils in the Cantwell formation along the northern foothills of the Alaska Range in Mount McKinley National Park has led to the correction of the correlation of these rocks, which were originally considered Tertiary. The description of these rocks has, however, been allowed to stand as printed on pages 62–63, in the section on Tertiary formations, though the formation has been correctly shown on the geologic map (pl. 1) as Cretaceous.

characteristics, and as the main features of those rocks in the Kuskokwim region have already been stated, reiteration here is unnecessary except to point out that as mapped on plate 1 possibly some rocks of Tertiary age have been included inadvertently. On the whole, however, the rocks are of Upper Cretaceous age and include some beds that are distinctly of marine origin and others that were laid down in fresh water.

In the area here designated as embracing Cretaceous rocks that extend from the Yukon River near Ruby well into the Koyukuk Valley, from the Hughes district to the Wiseman district, two different units that belong to this system have been distinguished. The older of these has been seen in the highlands that stretch northward from the Koyukuk River between the Dakli and Hogatza Rivers. This older assemblage of rocks was originally described under the name "Koyukuk group" and was said to consist of pinkish to reddish limestone, dark shale, slate and sandstone, and arkose, together with some lava flows and tuffs. In the Zane Hills, where these rocks were studied in most detail, no limestone beds were recognized and the group consists mainly of agglomerates and arkosic beds associated with basic effusive rocks and cut by both basic and acidic intrusives. The rocks are thoroughly indurated and have been considerably deformed. A single fossil collected from the limestone that crops out on Waite Island, some 40 miles upstream from the Zane Hills, was identified as of Lower Cretaceous age. Admittedly this is a rather inadequate basis on which to rest a definite correlation, but the facts that this assemblage of rocks definitely underlies known Upper Cretaceous rocks and that no recognized Jurassic rocks have ever been reported in the whole region lead one to regard that assignment as entirely acceptable.

The younger member of the Cretaceous system has long been recognized and in the Koyukuk Valley was called the Bergman group—a name that has been generally used, though in the area near the Yukon the name "Shaktolik group" has been adopted. Martin has suggested a more refined splitting up, but his subdivisions have not yet been given a try-out in field practice. Near the Yukon the lower member of this sequence consists of a massive conglomerate whose component boulders consist of a great variety of different rocks, including granite, gneiss, and metamorphic schists. Similar conglomerates have been recognized in the Koyukuk Valley, especially at Tramway Bar and on the Alatna River. This conglomerate member near the Melozi is about 100 feet thick and is succeeded by fine-grained sediments, mainly sandstones and arkoses, which are generally feldspathic. Some shales are associated with the sandstones and are usually dark-colored and contain much carbonaceous material. As a rule the beds are rather massive and do not show pronounced stratification. Throughout the area these rocks are considerably folded and somewhat faulted, so that the area they cover is considerably greater than their actual thickness would perhaps suggest, but such measurements as have been made indicate that this series embraces a sequence of beds at least 10,000 feet thick, with neither the top nor the bottom definitely exposed. As mapped on plate 1, the upper limit of the Cretaceous rocks of the Melozi-Koyukuk tract is believed to be indicated with a fair degree of fidelity. It must be admitted, however, that the distinction between the known Cretaceous and Tertiary cannot be sharply drawn, so that possibly in places there was no break in sedimentation between the two periods. The solution of this whole question, however, must await further investigation, though from the meager information now at hand it is believed that probably there was a break between the two.

The area of Cretaceous sedimentary rocks in the Hot Springs and Rampart districts embraces representatives of both the Lower and Upper Cretaceous series, though the Lower Cretaceous member appears to be the dominant one. The rocks of the older series are principally slate and quartzite, but locally in the vicinity of granitic intrusives some of these rocks have been rendered schistose. The recognized Upper Cretaceous beds have been found only in the vicinity of Wolverine Mountain, where they are black, rather massive impure sandstones and shales. The fossils from the Lower Cretaceous beds are mainly marine forms, though some plant remains have been collected from them. On the other hand, the fossils from the Upper Cretaceous beds are about equally divided between plants and marine forms, and the recognized forms are rather more numerous than those from the older rocks. The Lower Cretaceous beds rest unconformably on highly deformed and schistose Paleozoic rocks. No definite information is yet available as to the relations between the Upper and Lower Cretaceous beds, but it seems probable that they are separated by an unconformity. The top of the Upper Cretaceous sequence is not known, so that the relation of the series with the Tertiary has not been demonstrated, but the difference in structure between the members of the two systems definitely suggests a strong stratigraphic break.

In the area along the Yukon from Woodchopper eastward nearly to the international boundary both Upper and Lower Cretaceous rocks have been recognized. The Lower Cretaceous beds of this region have been designated the Kandik formation. They consist of black shale and rather thin beds of gray to dark-brown sandstone. Associated with these beds at intervals are quartzitic layers that serve as horizon markers. The upper part seems to be composed principally of sandstone and fine conglomerate. The beds are relatively little folded or faulted. Neither the top nor the bottom of this unit has been definitely recognized, but the known section embraces at least 2,400 feet of beds.

A fair number of collections of fossils have been made from these beds, most of which comprise marine invertebrates, though one contains plants. These fossils are now regarded as definitely establishing the Lower Cretaceous age of the beds from which they were obtained.

The Upper Cretaceous rocks of the Yukon region near Woodchopper have not been differentiated with completeness from the overlying Tertiary rocks. These rocks occur in a belt about 85 miles long, from east to west, and 1 to 15 miles wide, from north to south. They consist of impure greenish-gray to almost black sandstone, graywacke, sandy shale, and beds ranging from grit to coarse conglomerate. The coarsest conglomerate lies near the top of the section and may mark the separation between the Tertiary and the Cretaceous. This member is of considerable economic significance, for it seems to mark concentration of mineralized material from the then old land, and where these concentrations of the past have been reconcentrated by the later streams they have in places given rise to gold placers that are now being mined. Obviously, not all parts of this earlier concentration were equally rich, and consequently even when later reconcentrated they do not everywhere yield modern placers that can be mined at a profit. These Upper Cretaceous strata also in places contain coal beds that have been locally developed to supply small quantities of fuel.

The region south of the Yukon River in which these Upper Cretaceous rocks occur seems to have been subjected to much greater deformation and igneous intrusion than that north of the river in which the Lower Cretaceous rocks crop out. There is, therefore, the apparently anomalous condition that the younger beds are on the whole somewhat more deformed and metamorphosed than some of the older rocks. No accurate measurement of the thickness of these Upper Cretaceous beds has been made, but Mertie states that from the general evidence available he considers that 4,000 feet may be given as a minimum estimate. Evidence as to the age of the beds is by no means unequivocal. They have yielded both plant and animal fossils, but Martin was inclined to assign all of them to the Upper Cretaceous, in spite of the paleobotanic evidence, which indicated that some of the fossils were Tertiary. Mertie, however, while admitting that the fossils may not be sufficiently diagnostic for precise stratigraphic correlation, inclined to the interpretation that probably the early Tertiary was not sharply separated from the late Upper Cretaceous, so that a gradual transition between the two took place, resulting in the apparent mingling of the faunas. He therefore accepted the paleobotanic determination but was unable to map the beds in which the plant remains occur as a separate formation and therefore grouped the beds as Upper Cretaceous and Eocene.

Cretaceous beds have been definitely identified in the Chisana-White River district in the extreme southeast corner of the Yukon region, but have not been represented as such on the accompanying map (pl. 1) because they are so closely associated with rocks of other ages that their differentiation has not yet been possible. In fact, the description of these rocks is so intimately intermingled with the description of the Jurassic rocks that the statements given seem to apply equally to both. The rocks that have yielded Cretaceous fossils are dominantly shales and argillites, with lesser quantities of interbedded graywacke. Some fine conglomerate was seen and a little limestone. The Jurassic and Cretaceous beds are tilted, but except where cut by later intrusives they show no signs of metamorphism. Faults are common, and certain of the Cretaceous beds lie immediately adjacent to the Devonian rocks, from which they are separated by a profound fault. The fossiliferous rocks of Jurassic and Cretaceous age appear to have a minimum thickness of 3,000 feet. The Cretaceous fossils were obtained from rocks that lithologically cannot be differentiated from those of Jurassic age. All the Cretaceous fossils are marine forms and are identified as belonging to the Lower Cretaceous fauna, the most diagnostic species being *Aucella crassicolis*.

NORTHERN ALASKA

Probably the most uninterrupted area of Cretaceous rocks in Alaska is the great plateau and plains region north of the Brooks Range, in northern Alaska. The continuity of the subdivisions of the Cretaceous system in that area is somewhat masked by the fact that so large a part of the region is still unexplored, so that the bedrock in many places can as yet only be conjectured. This northern area of Cretaceous rocks is known to embrace parts of the Anaktuvuk, Colville, Barrow, Wainwright, and Lisburne districts and probably extends to include the mapped Cretaceous areas in the Canning district as well. In addition, smaller areas of Cretaceous rocks are recognized in the Noatak and Kobuk districts, and probably these same rocks form extensive tracts in the Selawik district, although only a small part of that district has been examined by geologists.

Rocks of Lower Cretaceous age were first recognized in northern Alaska by Schrader on the Anaktuvuk River, a tributary of the Colville, and described under the name "Anaktuvuk series" (now called Anaktuvuk group). Subsequently similar rocks were identified in the valleys of the Chandler, Killik, Etivluk, Nuka, Utukok, Kokolik, and Kukpowruk Rivers and near Cape Lisburne, thus forming a more or less obviously continuous strip, except where unexplored country intervenes, more than 350 miles long and averaging about 15 miles wide. Throughout this strip the group consists dominantly of sandstone with subordinate amounts of shale and lesser amounts of conglomerate and grit. Usually the sandstone is in fairly massive beds whose color is dark grayish or greenish brown, giving the hills composed of these rocks a dark appearance when viewed from afar off. The rocks are usually well indurated and so firmly cemented that they display no tendency to crumble but instead weather into rather angular fragments.

At most places the beds have been folded so that they stand at average inclinations of at least 45° and near the mountains, where the diastrophism appears to have been most intense, some of the folds appear to have been overthrown. This is apparently the condition near Cape Lisburne, where the normal sequence of beds has been reversed. Although in detail the structure of these rocks shows many complexities, in general the prevailing dip is northward, so that on the whole younger rocks are progressively exposed in that direction. No detailed measurements of the thickness of this group have been made, and estimates from generalized observations have varied from 2,000 feet by Schrader for the section seen on the Anaktuvuk to Collier's estimate of not less than 5,000 nor more than 15,000 feet for the group near Cape Lisburne. W. R. Smith and the writer estimated the thickness in the central part of the area, where they saw these beds most closely, as in the neighborhood of 10,000 feet. The conditions under which so great a thickness of sediments was laid down in relatively shallow water, as shown by the abundant ripple marks and other evidences of near-shore deposition, are difficult to understand. Only a few fossils have yet been obtained from this extensive exposure of rocks, but they are marine forms that have been identified as belonging to a Lower Cretaceous fauna. An interesting fact of economic significance in connection with these rocks is the discovery in the valley of the Etivluk River of rich oil shales that may be the mother rock for some of the oil that has been found in seepages much farther north in the same region. The precise stratigraphic position of these oil shales has not been determined, but apparently they occur rather near the base of the Lower Cretaceous section.

Separated by a marked angular unconformity in places from the Lower Cretaceous series and forming in general practically all of the bedrock exposed at the surface in the region north of those rocks, even to points on the Arctic coast, is a thick sequence of sedimentary beds consisting dominantly of sandstone and shale that are considered of Upper Cretaceous age. Some of the localities where these rocks are exposed have long been known, though the age of the beds was not always correctly identified. Thus, near Corwin these rocks long ago furnished some coal to the vessels of the whaling fleet. On the Anaktuvuk, Schrader in 1901 recognized beds representative of the Upper Cretaceous series which he described as the Nanushuk "series", though he did not include in it all the rocks now regarded as of Upper Cretaceous age in that valley. Covering as they do tens of thousands of square miles, these rocks show numerous minor variations in composition and lithology, but on the whole they have constant general features. In the main, near the base the section consists principally of sandstone, which is probably of marine origin, though it contains some plant fragments and woody material that were derived from the nearby lands. The middle part of this assemblage of rocks is composed dominantly of shale, with subordinate amounts of sandstone. It is in this portion that coal beds are most numerous and show by their presence that they and the rocks with which they are associated were formed in swamps and sheltered waters essentially under land conditions. The upper part of the section appears to consist mainly of marine sediments in which sandstone is much more abundant than shale. All these rocks appear to have been accumulated in shallow water, as ripple marks, mud cracks, and other evidences of near-shore deposition are common. Varying degrees of deformation have affected these rocks in different parts of the region. Thus, near their southern limits they have been rather strongly folded and faulted, dips of 45° or more being not at all uncommon. Farther north, however, and nearer the coast, the folding has been less intense, and broad open folds or even dips of 15° or less are by no means unusual. Various estimates but few reliable measurements of the thickness of beds included in the Upper Cretaceous section exposed in northern Alaska have been made. The estimates vary somewhat, but few of them indicate a thickness of less than 10,000 feet of strata, and some of them run as high as 17,000 feet. Therefore, although no definite figure can yet be accepted, it is evident that these beds have a very great thickness, which is probably in excess of 10,000 feet.

The age of the beds assigned to the Upper Cretaceous is now rather firmly established through the collections of both plant and animal fossils that have been identified. There is still, however, some difficulty in reconciling the paleobotanic evidence from the rocks in the vicinity of Corwin that are correlated with this series, because the old identification of the plants near Corwin led to the conclusion that they came from Jurassic beds. The more complete evidence obtained later from beds less than 50 miles distant and on the same strike as these rocks has necessitated a review of all the facts, and from that review the conclusion was reached that the beds near Corwin should be correlated with the Upper Cretaceous rocks and that the apparent discrepancy in the paleobotanic evidence was due to the lag in the response of the plants to the change in geologic conditions.

The coal beds that form an integral part of the Upper Cretaceous section in northern Alaska constitute a great though as yet practically untouched asset, of potential value in any developments that may be undertaken in this vast northern area. Thus, in the area near Corwin there are 34 coal beds that represent an aggregate thickness of more than 135 feet of coal, and 15 of these beds, each 3 feet or more thick and the largest 30 feet thick, represent 115 feet of coal. In the Kukpowruk-Utukok section 69 beds were measured, each of which is at least 3 feet thick and the largest 20 feet thick. After eliminating duplication, these beds represent a total of 187 feet of coal. Other parts of this area that have not been studied in so much detail indicate comparable sections of coal. The quality of these coals differs considerably in relation to the folding that the beds have undergone. Thus, in the less intensely folded areas the coals are in the main good-grade lignites, but in the highly folded areas many of the beds contain coal of bituminous rank.

Probably Cretaceous rocks form the bedrock of much of the unexplored region east of the Colville River to the Canning River. In the valley of the Canning River Leffingwell found exposures of coarse gray sandstone along the northern flanks of the Sadlerochit Mountains. The sandstone contains no fossils and is unlike any of the other rocks seen in the district, and little was learned about it except that it is younger than the nearby Jurassic rocks and older than Pliocene. Leffingwell tentatively assigned these beds to the Tertiary, but it now seems more likely that they form part of the Upper Cretaceous sequence. This conclusion receives some additional support from the fact that Leffingwell, who is the only one who has examined the Canning River locality, correlated the beds there with the exposures at Peard Bay, which are now also included in the Upper Cretaceous series.

In the Noatak district the only recognized area of Cretaceous rocks is a small tract near the central and headward part of the Nimiuktuk River. Lithologically the section in this area appears to be similar to the Lower Cretaceous rocks that crop out in the valleys of the tributaries to the Colville some 20 miles to the north. Apparently it is an infaulted block of these rocks and probably extends eastward to connect with the narrow band of Lower Cretaceous rocks that form the bedrock in part of the Etivluk Valley, 50 miles to the east. The preservation of this block within the mountain area is of significance in indicating that the Cretaceous rocks once extended far to the south of the present southern outcrop of the main body of these rocks, before the mountains arose on their present site.

Cretaceous rocks flank most of the southern boundary of the Kobuk Valley and in places crop out even north of the river. In the main these occurrences mark the northern extension of the rocks of that age in the Yukon region that have been described as forming the greater part of the country from the Melozi River to parts of the Koyukuk Valley and adjacent areas. The lowermost members of this system are coarse conglomerates, which unconformably overlie Paleozoic or older metamorphic rocks. These rocks are thoroughly indurated and are as a rule strongly resistant to weathering so that they form conspicuous pinnacled ridges. Gradually higher in the section the conglomerates give way to sandstones and finer-grained sedimentary rocks, usually of rather uniform texture and greenish-gray color. Some shales are interspersed among the sandstones, but as they are less resistant they form few notable exposures. So far as known the rocks are to be correlated in all essential respects with the similar rocks in the Yukon region near Nulato or with the group of Upper Cretaceous rocks in the Melozi and Koyukuk districts.

Practically none of the Selawik district has been examined geologically, so that little is known regarding the formations that occur there. However, a small part of the extreme headward part of the valley, which abuts against the head of the Pah River, a tributary of the Kobuk, and the Dakli River, a tributary of the Koyukuk, was examined in the course of an exploratory survey. This part was seen to lie near the junction between the supposed Lower Cretaceous rocks of the Zane Hills on the south and the Upper Cretaceous rocks that form the hills south of the Kobuk on the north. It seems probable that most of the surface rocks of the Selawik Basin are Cretaceous or later.

SEWARD PENINSULA

Forming the bedrock throughout most of the eastern part of Seward Peninsula in the Shaktolik and Buckland districts and extending eastward into the Nulato and adjacent districts of the Yukon region is a great thickness of beds that are essentially a unit and have been assigned to the Upper Cretaceous series. At the base of this sequence is a conglomerate of marine origin that has been called the Ungalik conglomerate. It rests unconformably on the underlying formations and is composed of the material worn from these older rocks. No measurements of the thickness of this member have been made, but from the extent of country it covers and its structure it is believed to be at least 1,000 feet thick. Overlying the Ungalik conglomerate is a thick sequence of sandstones and shales which are known as the Shaktolik group (pl. 9, *B*). The lower part of this group is composed dominantly of sandstone, and the upper part of dark shales. Probably coal beds occur in this group in Seward Peninsula, as they do in rocks correlated with it in the Nulato region, but none of economic significance have been disclosed by the rather cursory examinations that have been made. The beds have been extensively deformed along axes trending northeast, and some faulting has interrupted the normal sequence. Vertical dips are not unusual, and dips steeper than 45° are the rule. The structure has not been determined with enough exactness to allow any reliable estimate of the thickness of the beds involved. However, the series is very thick, perhaps as much as 10,000 feet or more.

A small infaulted block of what is regarded as the equivalent of the Ungalik conglomerate occurs in the valley of the Tubutulik River. This area is about 20 miles long and from 2 to 3 miles wide. The boulders are almost exclusively limestone derived from the Paleozoic rocks that unconformably underlie these beds. The age of the strata was determined from fossil plants contained in some of the limy sandstone layers interstratified with the boulder beds. The most significant feature of this occurrence is that it shows that these Cretaceous rocks once extended far to the west of the present limit of the main body and in the intervening area have subsequently been removed by erosion or some other geologic process.

CENOZOIC ROCKS

TERTIARY SYSTEM

The Mesozoic era, or the era of intermediate forms of life, was followed by the Cenozoic era, or that in which the forms took on more and more modern aspects. In spite of this implied recency, it should be realized that in terms of years the beginning of this era was far in the past, being estimated as 10 million to 60 million years ago. There has therefore been a long span during which many processes have been active in making new deposits and new land forms and in carving away and altering those features that were made during earlier ages. Although it is known that in Alaska during Cenozoic time there have been movements of the crust, amounting in places to thousands of feet of uplift, with profound faulting and intense crumpling which here and there deformed beds deposited as flat-lying sheets until they stand vertical or are even overturned, it appears that on the whole the major features of the country as we now know them were more or less blocked out in general appearance at the beginning of the Cenozoic era. Information is not yet in hand from which to reconstruct the successive stages by which the changes have been brought about. All that now can be done is to give a brief summary of some of the more outstanding events that have been recognized in the various geographic areas, with a running interpretation of the facts that are disclosed by the geologic record of the major subdivisions of Cenozoic time.

Descriptions of the different Tertiary formations are to be found in many of the reports issued by the Geological Survey on various areas in Alaska and a comprehensive technical study of the various fossil plants that have been collected from these formations, together with general notes on the Tertiary deposits, has recently been published by the Geological Survey. This general report [24] should be consulted for more detailed information regarding the plants that lived in that period and the comparisons that have been drawn between them and floras throughout the world. This consultation would reveal the fact that some of the forms are such as are now characteristic of tropical or subtropical regions, others of more temperate regions, and some of even boreal habitat. Furthermore, certain of the forms are now exclusively New World in their distribution, others are restricted to eastern and southern Asia and Australia, and still others are characteristically eastern Asiatic, though occurring elsewhere. In other words, the interpretations given in this report would reconstruct and rivivify these now extinct floras and bring to mind those past landscapes, so that their history would be made evident.

SOUTHEASTERN ALASKA

Sedimentary rocks that are definitely recognized as of Tertiary age occur in several small and widely separated areas in southeastern Alaska. At none of these places is a complete section of these rocks exposed, and at most of them the sedimentation was interrupted at frequent intervals by outpourings of lava and the accumulation of volcanic ejecta and tuffs. As no rocks of definitely determined Upper Cretaceous age have been recognized in southeastern Alaska, the Tertiary beds everywhere unconformably overlie Lower Cretaceous or older rocks. According to Buddington, the only Tertiary epoch represented by sedimentary rocks in this region is the Eocene, the earliest epoch of that period. The oldest beds of this series are coarse sandstone, with basal and intercalated beds of conglomerate, which have been identified on Prince of Wales Island, Cleveland Peninsula, and Kupreanof, Kuiu, and Admiralty Islands. These beds are at least 1,350 feet thick. Overlying these distinctly sedimentary beds are rhyolitic and andesitic volcanic rocks associated with minor amounts of sedimentary material. This member is most noteworthy on Gravina, Zarembo, Kupreanof, and Kuiu Islands. Still higher in the Tertiary section are basaltic and andesitic lavas associated with relatively thin beds of sedimentary origin. These rocks are recognized especially on Kupreanof, Kuiu, and Admiralty Islands.

A significant economic feature in some of the sections of these rocks is that in places thin beds of coal form an integral part of the sequence. At Kootznahoo Inlet, on Admiralty Island, coal beds that have been mined on a small scale occur in the lower member of the Tertiary sequence, and at Murder Cove, on Admiralty Island, the coal beds appear to be included in the upper member of the Eocene series. All the fossils so

[24] Hollick, Arthur, The Tertiary floras of Alaska: U. S. Geol. Survey Prof. Paper 182, 185 pp., 1936.

far obtained from these beds are land plants, no marine animals having been recognized in any of the sediments. The evidence from the flora, together with the physical aspects of the rocks, indicates that the coarser deposits were formed more or less as alluvial fans near the mouths of swift streams debouching from a highland mass, and that the finer deposits were laid down along the flood plains of the then existing streams. In most places the beds are rather flat lying, though they have been subjected to some mountain-building stresses, so that dips of 10° or so are common and dips of more than 20° are by no means unusual. That at least some of these movements were not violent in character is shown by the presence here and there of buried forests of Tertiary age in which many of the tree stumps are still standing upright. Such an occurrence is reported about 3½ miles south of the west headland of Port Camden, where six such stumps were counted in a tract 50 yards square. Remnants of another such forest are exposed on the west side of Keku Strait about 4 miles southeast of Point Camden.

ALASKA GULF REGION

In the Alaska Gulf region Tertiary deposits have been recognized at several points, and some of the deposits are sufficiently extensive to be shown on the accompanying map (pl. 1). Among these places the most significant, named in geographic order from east to west, are the Lituya, Yakutat, Yakataga, Katalla, and Cordova districts.

In the Lituya Bay district the known Tertiary rocks comprise well-indurated sandstone, shale, and conglomerate, with a few thin beds of coal and some tuffaceous strata, trending in general northwest. From the character of the fossils collected from these beds, most of them being marine forms of life, it has been determined that most of the beds were laid down in ocean waters. The beds of coal, however, show that some of the members of the sequence were formed under terrigenous conditions, so that there was an oscillation of the strand line whereby at different times during this period the region was alternately below and above sea level. From the fossils it is further learned that the lowermost Tertiary rocks exposed are of upper Miocene age but that the higher beds, which are mostly shales, are probably Pliocene. The beds have been subjected to mountain-building forces whereby they have been thrown into folds whose dips range from 30° to 60° SW. Several thousand feet of beds are included in the Tertiary section, and if there is no reduplication through folding and faulting they may possibly be as much as 12,000 feet thick.

About 100 miles west of the Lituya Bay localities of Tertiary rocks, in the vicinity of Yakutat Bay, are small areas in which cross-bedded sandstone, shale, and clay, with some lignitic coal seams, have been identified as of Tertiary age. In general these rocks are much less thoroughly indurated than the other rocks of the region and disintegrate readily under the influence of weathering. The rocks do not show complex folding or faulting, but instead have been broadly tilted, so that dips as high as 45° are by no means uncommon. The character of the beds and the fossils collected from them indicate that they were formed on land and do not include marine strata. So far only a few lots of plants have been collected from these beds, and these suggest correlation with the Pliocene rather than older Tertiary floras.

In the Hitchcock, Samovar, and Chaix Hills, immediately south of Mount St. Elias, Russell long ago found deposits which he called the Pinnacle "system" and described as comprising conglomerates, sandstones, and shales, with a few thin and unimportant coal seams, a measured incomplete section of which showed a total thickness of about 1,800 feet. The whole assemblage is described as having been derived from morainic material, though the upper part of this section appears to have been laid down under marine conditions and contained marine shells, whereas the coal beds in the lower part of the section contained fossil land plants. Identification of the age of these beds from both their flora and their fauna indicated that they were formed either late in the Tertiary period (probably Pliocene) or early in the Quaternary period (Pleistocene). Even though most of the rocks of the Pinnacle "system" have been only slightly consolidated, they have been uplifted and tilted so that now they stand in places 5,000 feet or more above the sea, and locally the beds have an inclination of 40° or more.

Farther west, in the Robinson Hills of the Yakataga district, nearly 8,000 feet of beds have been identified as Tertiary, though the assignment of the different members to specific series within that system is still open to inquiry. According to Maddren, the oldest member of the section, which he assigns to the Eocene, consists of fine gray arkose and black slate with some coal beds. Above these beds and probably of Miocene or Oligocene age are calcareous shales, thin limestones, and thin beds of conglomerate in the basal portion, overlain by more quartzose sandstones and shales. Succeeding these beds and provisionally regarded as upper Miocene are beds of buff sandstone and shale with intercalated conglomerate. The top member of what Maddren regarded as Tertiary consists of shales and flaggy sandstone and conglomerate, assigned by him to the Pliocene. Still higher in the section are boulder-bearing sandstones and shales, which, although regarded by Maddren as Pleistocene, he correlated with Russell's Pinnacle "system," which, as has already been shown, is believed to be, in part at least, of Tertiary age. The bulk of the members forming the Tertiary system in the Yakataga district were deposited under marine conditions rather near the old shore line. These rocks may have considerable economic significance, for they form the bedrock in the areas where petroleum seepages have been found, and beds of coal occur in part of the section.

Probably the most thoroughly studied beds of Tertiary age in this region are those in the Katalla district, because there the beds contain a considerable number of coal seams of high rank. In this district Martin recognized two rather distinct sections, one to the north and one to the south of Bering Lake. The section north of Bering Lake embraces three separate units, which, named in ascending order, are the Stillwater, Kushtaka, and Tokun formations. The Stillwater formation comprises shale and sandstone beds more than 1,000 feet thick, dominantly of marine origin. The Kushtaka formation consists largely of arkose with many coal beds and some shale and sandstone. It was formed dominantly under land conditions and is about 2,500 feet thick. The Tokun formation consists of sandstone and shales with thin flaggy sandstones and a few calcareous concretions. It is dominantly of marine origin and comprises about 2,500 feet of beds. South of Bering Lake is the Katalla formation, which is about 6,500 feet thick. The exact correlation of this formation with those to the north of the lake has not been determined, though it is probably older than the Stillwater formation. All the evidence points to the likelihood that all four of these formations are post-Eocene and that the Tokun is probably of Miocene age and the Kushtaka and Stillwater formations are Oligocene or Miocene. The known seepages of petroleum in the Katalla district, which is the only district in Alaska from which petroleum has been produced commercially, all occur in areas where the bedrock is regarded as belonging to the Katalla formation. This fact, however, cannot be interpreted as proof that the petroleum originated in these rocks, as it may have seeped upward through them from a deeper source.

The extensive coal deposits in this area are, so far as now known, limited to the Kushtaka formation. These coals range from bituminous through semibituminous and semianthracite to anthracite and, although they will be rather costly to mine and develop, are among the valuable mineral reserves of the Territory. As an indication of the former greater extent of these Tertiary rocks the isolated occurrence of them on Middleton Island, far out in the Pacific Ocean, is of particular significance. The rocks on this island are described by Capps[25] as moderately indurated sandstone and conglomerate that in places are inclined 30° or more and have been beveled off by wave erosion, and later gravel and sand have been laid down on the truncated edges. No fossils have been obtained from these beds, so that their age has not been definitely proved, but their lithology and general features leave little room to question this assignment and suggest that probably they will prove to be correlative with rocks in the lower part of the Tertiary system.

Possibly rocks of Tertiary age occur elsewhere in the Alaska Gulf region, but if so their presence has not been recognized, and if they should be found, they will probably prove to occur in discontinuous patches of little areal extent.

COPPER RIVER REGION

Although dominantly the Tertiary rocks of the Copper River region are of volcanic origin, there are also erratically distributed areas of sedimentary beds. These accumulations consist of conglomerate, finely variegated clays, and lenses of coal, all of which were deposited in fresh water in depressions on the old land surface. None of these areas of sedimentary rocks occupy more than a few square miles, and they are therefore too small to be represented on the accompanying map (pl. 1). A few sections of these Tertiary beds have been measured, especially in the vicinity of Skolai Creek, and show thicknesses of as much as 300 feet of beds. The beds have been little deformed, though they may have been broadly uplifted. Most of the plant fossils that have been collected from these beds are identified as comparable with the Kenai flora, which, typically, is now considered to be Eocene.

COOK INLET-SUSITNA REGION

The Cook Inlet region is the Alaskan area where certain Tertiary formations have been earliest recognized, most typically developed, and more thoroughly studied than anywhere else in the Territory. As will be recognized from the geologic map (pl. 1), the Tertiary formations of this region may be grouped roughly together into three principal areas—namely, first, in the lowland east of the southern part of Cook Inlet; second, in scattered exposures west of the inlet and in the great lowland at the head of the inlet, stretching far northward along the valleys of the Susitna River and its tributaries; and, third, in the Matanuska Valley and adjacent areas. Probably a much greater areal extent of these rocks would be displayed if the overlying cover of Quaternary deposits were stripped off, especially in the first two areas mentioned. Thus, the entire western part of the lowland of Kenai Peninsula from Kachemak Bay to Turnagain Arm is probably underlain by Tertiary rocks, though they are represented on the map as exposed at the surface only in the southern part of this tract. In addition the rocks of this system occur as separated masses in nearby areas. In the large area mapped the Tertiary rocks consist of about 2,000 feet of beds composed dominantly of sandstones and shales.

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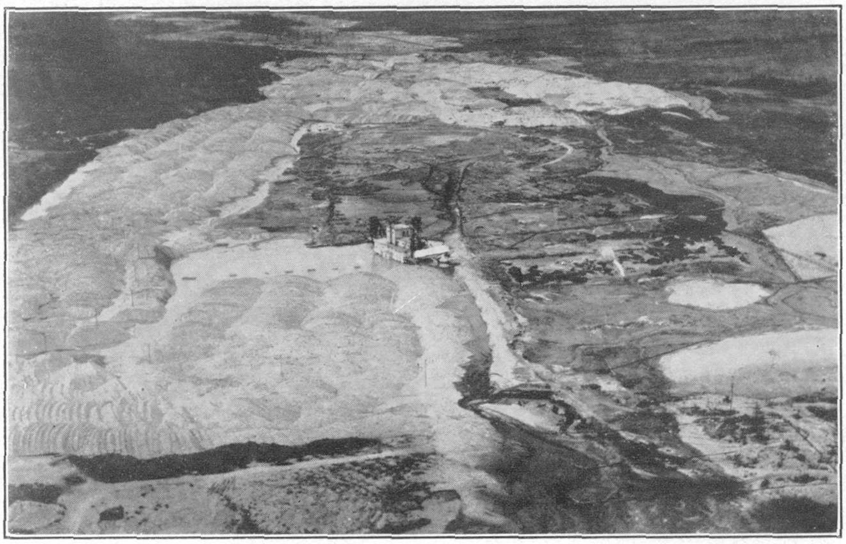
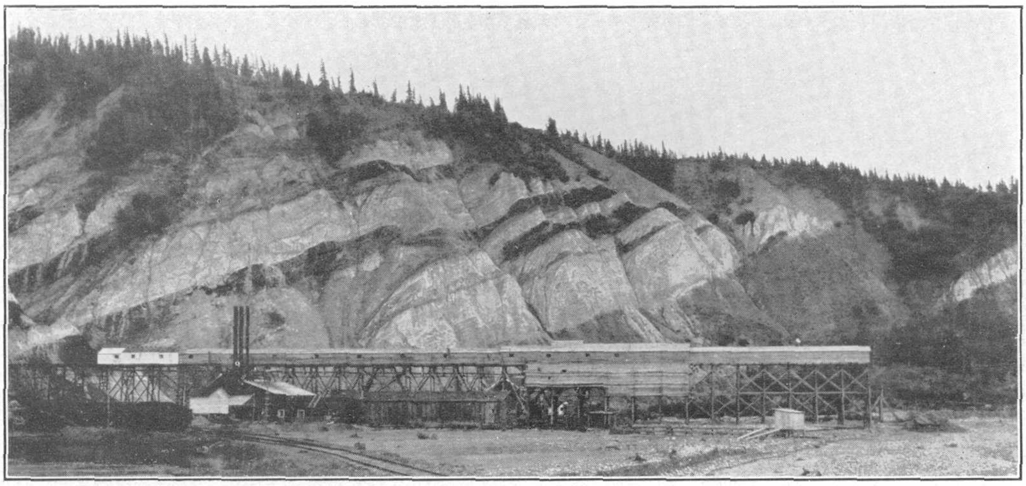
[25] Capps, S. R., Air reconnaissance of Middleton Island, Alaska: Jour. Geology, vol. 41, pp. 728–736, 1933.



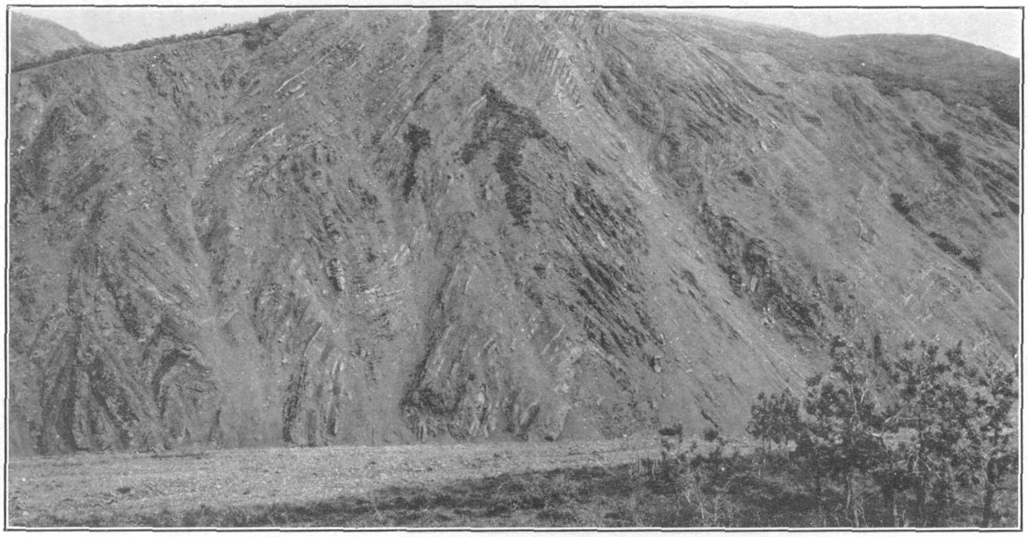
A. EXTENSIVE PLACER MINING IN THE QUATERNARY DEPOSITS NEAR FAIRBANKS.

The auriferous gravels of the Territory have yielded placer gold to the value of nearly $300,000,000. The material of many of these deposits near Fairbanks is permanently frozen.

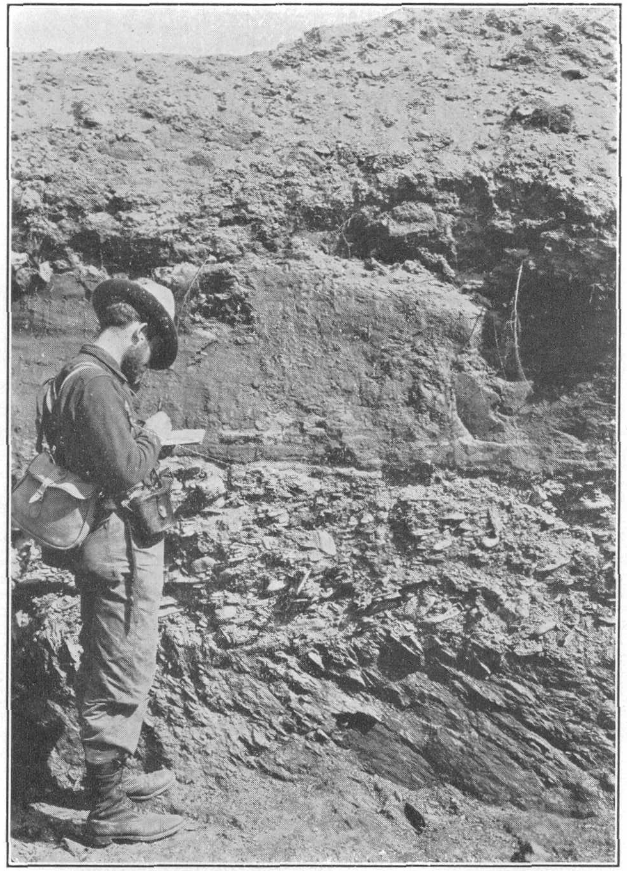


B. THICK BEDS OF COAL IN VALLEY OF HEALY RIVER NEAR SUNTRANA, INTERSTRATIFIED WITH TERTIARY SANDSTONES AND SHALES

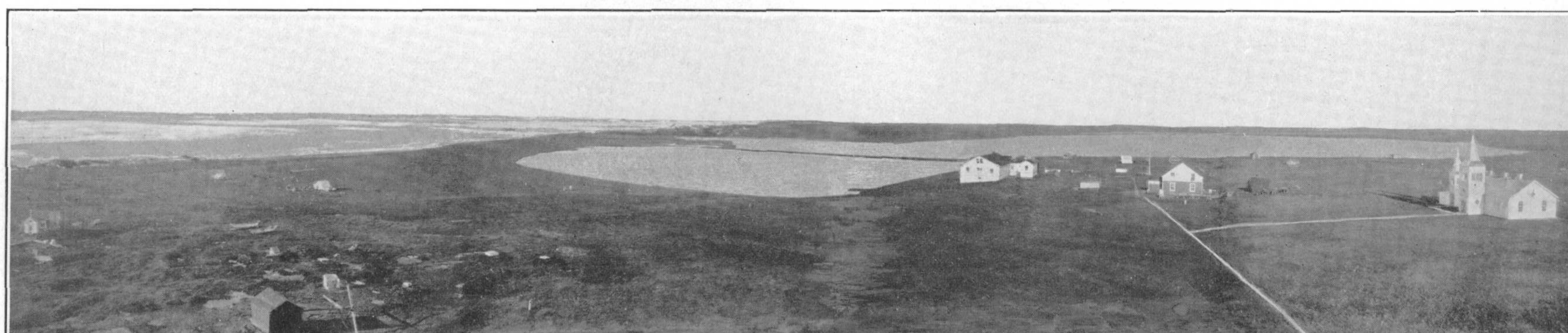
The greatest amount of coal mined in the Territory comes from this area.



C. DEFORMED BEDS OF SANDSTONE AND GRIT THAT FORM PART OF CANTWELL FORMATION, OF UPPER CRETACEOUS AGE, EXPOSED IN VALLEY OF EAST FORK OF TOKLAT RIVER, MOUNT McKINLEY NATIONAL PARK.



A. SECTION OF PLACER GRAVELS NEAR NOME RESTING ON HIGHLY METAMORPHOSED SCHIST BEDROCK.



B. THE COASTAL PLAIN IN ENVIRONS OF BARROW.

The northernmost settlement on the North American Continent.

Some conglomerate is interbedded at irregular intervals throughout the section, and numerous coal beds are exposed. In general the rocks are not strongly indurated, but they are firm enough to stand up as cliffs, some of which are several hundred feet high, where the rocks have been undercut by the sea. Locally, cementation by iron-bearing or calcareous material has given the rocks more than ordinary hardness. None of the beds have afforded fossils that give indication that the beds in which they occur were formed under marine conditions and, instead, all bear evidence that they were formed on land. Martin estimates that between 3 and 5 percent of the entire thickness of the formation in this area is composed of coal beds each of which is from 3 to 7 feet thick. These beds have long been known as the Kenai formation and for many years were considered to represent the so-called "Arctic Miocene." Later this age classification was modified so that now the typical Kenai flora is considered to belong to the upper part of the Eocene series. Collections from the type area, however, are by no means as comprehensive as is desired, and the identification of the age of the beds has been made out by piecing together the evidence from scattered localities, some of which are remote from the type section.

In the area to the west of Cook Inlet and at its head the general lithology of the Tertiary deposits is on the whole identical with that on the east side of the inlet. In these places, however, the exposures of the Tertiary rocks are usually much smaller, so that only fragmentary evidence in regard to the formation as a whole can be seen. Thus scattered areas of these rocks have been recognized at a number of places along the banks of the Susitna, Yentna, Skwentna, Beluga, and Chulitna Rivers and Straight Creek and on the shores of the inlet near Tyonek. In general the beds are more or less thoroughly consolidated and have been somewhat deformed, so that they have a distinct dip. Near the mountains bordering the lowland the beds show more induration and more intense folding, so that in those places dips approaching vertical are not unknown. In nearly every place where any extensive section of these rocks is exposed the sequence contains beds of lignitic coal, some of which are fairly thick. Some of the coal beds have been slightly developed to supply fuel for local needs. In places in this area the sedimentary beds assigned to the Tertiary are at least 2,000 feet thick. Like the section of that system on Kenai Peninsula, the Cook Inlet section contains no beds of marine origin, was evidently accumulated entirely under terrigenous conditions, and is of Eocene age.

The Tertiary sedimentary rocks of the Matanuska district are divisible into three principal units—the Chickaloon formation, the Eska conglomerate, and an unnamed assemblage of arkose, conglomerate, and shale. The Chickaloon formation underlies the Eska conglomerate, but the stratigraphic position of the arkose member is uncertain, and it may in part be the equivalent of either or both of the other two formations or entirely separate. The Chickaloon formation is a rather monotonous succession of shales and sandstones, the shales predominating. The individual beds are not persistent over considerable areas, and the rocks are in general only moderately indurated. Numerous coal beds occur in the section, and the general area in which this formation crops out is the principal productive bituminous coal field of Alaska at the present time. The beds are considerably folded and faulted, and some of them have been intruded by basic igneous rocks. The better grades of coal are found in the areas that have experienced the greater amount of deformation and intrusion. Accurate measurements of the total thickness of this formation have not been made, but the best estimates place it as more than 2,000 feet. The fossils contained in these rocks have all been determined as characteristic of the Kenai formation and therefore of Eocene age.

The overlying Eska conglomerate is in places as much as 3,000 feet thick. As the name implies, it is composed dominantly of a coarse bouldery agglomeration, with which are associated some thinner sandstone beds. Because of its greater resistance to weathering the conglomerate forms conspicuous landmarks. The pebbles in general are well rounded, as if long subjected to attrition, and embrace a wide variety of rocks, most of which are of igneous origin. The Eska, like the underlying Chickaloon, has been folded and faulted, but because of its greater resistance to deformation has taken on structures of larger amplitude than those characteristic of the weaker shales and sandstones. The uppermost original members of the Eska conglomerate have been removed in part through erosion, so that the surface on which the overlying beds of lava, which also are of Tertiary age, were poured out was irregular and marks a pronounced unconformity. No conclusive evidence as to the age of this formation is yet available except that it is not older than Eocene. Possibly it is the equivalent of certain Miocene conglomerates known elsewhere in the coastal regions of Alaska.

So little is known of the relations of the arkose member of the Tertiary sequence in the Matanuska district that further mention of it at this time is hardly warranted. Possibly it is the marginal phase of parts of both the Chickaloon and Eska formations. In places it appears to have a thickness of at least 2,000 feet, and the few fossils that have been found in its beds indicate that their age is Kenai. On the whole this assemblage of rocks appears to have undergone more severe deformation than any of the other members of the Tertiary sequence, but this might be due to its closer proximity to the axes of mountain building rather than to a real difference in age.

SOUTHWESTERN ALASKA

In general throughout the Alaska Peninsula and the rest of southwestern Alaska the Tertiary deposits are of volcanic origin, but there are small scattered areas in which sedimentary rocks of this age form the bedrock. These sedimentary beds are of special interest because certain of them were laid down under marine conditions, whereas others were deposited in fresh water. The deposits of marine origin have been recognized especially in the tract between Herendeen and Balboa Bays, at Pavlof Bay, and on Unga Island. The lower of these deposits at Herendeen, Balboa, and Pavlof Bays consist of soft shales and sandstone grits and seem to be interlaminated with deposits of fresh-water origin, so that the sequence was undoubtedly laid down under oscillating conditions of the strand line whereby the region was alternately under and above the sea. The marine invertebrate fossils, as well as the plant fossils, agree in indicating that these rocks are of Eocene age. On Unga Island the general lithologic character of the lower part of the section resembles closely that in the Herendeen Bay area, but in the upper part conglomerates are far more numerous in the sections studied. At the type locality for this higher member, which is called the Unga conglomerate, the rocks appear to rest conformably on beds that are identified as Eocene. This relation, however, is not regarded as proved and seems likely not to be true in general, because the Eocene rocks appear to be much more thoroughly lithified and in general more deformed than the beds of the Unga formation. Moreover, the fossils from the beds at all localities correlated with the Unga formation have been identified as marine forms of Miocene age.

The Tertiary sedimentary beds of terrigenous origin in the Alaska Peninsula, in addition to those already noted, have been found in more or less discontinuous patches all the way from Cape Douglas, near Kamishak Bay, in the northeast, to and beyond Pavlof Bay, in the southwest. Throughout this tract the lowest sedimentary beds appear to be in general closely comparable with the typical Kenai formation, though they are underlain by pyroclastic igneous rocks and basaltic flows that are also of Eocene age. These sedimentary rocks consist of sandstone and shale with subordinate amounts of conglomerate and numerous beds of lignite. The thickness of this group of rocks is variable in different places and reaches a maximum of 5,000 feet. In all the places where these rocks have been studied except those noted above they were laid down under land conditions and were not intermingled with marine beds.

At one locality on the west shore of Herendeen Bay Tertiary sedimentary beds that appear to overlie the Unga conglomerate, of Miocene age, are exposed. These beds do not differ markedly in lithology from the other Tertiary beds in their vicinity, but they contain fossils which, though unsatisfactory for specific determination, suggest a possible Pliocene age. If this tentative determination should be corroborated by more extensive collections of fossils, it would show that there is no clearly marked stratigraphic break between the Miocene and Pliocene rocks in that locality.

In the vicinity of Kodiak Capps found definite evidence of Miocene or Pliocene beds near Narrow Point, at the northern entrance to Ugak Bay. At several other localities in the same general region are rocks whose age has been less definitely determined, but which are probably of Tertiary age. Among these localities may be mentioned those on Sitkalidak Island and Trinity Islands and on the southern coast of Kodiak Island. The recognized Miocene or Pliocene beds are rather massive, fine-grained gray to buff sandstone, which is usually firmly enough cemented to stand in steep cliffs though friable in hand specimens. The rocks assigned less definitely to the Tertiary system at the other localities appear on the whole to be somewhat more indurated, as if they had undergone more intense metamorphism or chemical alterations. This difference may be due to differences in age, or it may have been caused by the beds lying close to areas of intense deformation. All the Tertiary rocks have been folded, the dip of the recognized Miocene or Pliocene beds averaging 15° to 20° and that of the other Tertiary beds being usually much steeper. The fossils in the Miocene or Pliocene beds are marine organisms that have been found in comparable deposits elsewhere in Alaska and on the Pacific coast of the United States. Certain of the older Tertiary rocks appear to have been deposited under nonmarine conditions that allowed the formation of thin seams of coal and are regarded as comparable with parts of the Kenai formation.

YUKON REGION

There are three principal areas in which recognized Tertiary rocks are most extensively developed in the Yukon region. These are in the Alaska Range and along its northern foothills, in the Koyukuk-Dall River area, and in the Eagle-Fortymile district. In the Alaska Range province three distinct types of deposits that differ not only in lithology but also in age and geographic distribution were laid down during Tertiary time. These deposits are, in ascending order, the Cantwell formation, the coal-bearing formation, and the Nenana gravel. The Cantwell formation (pl. 10, *C*) has been recognized as a more or less continuous formation along the entire northern flanks of the Alaska

Range, from a point near the head of the Tonzona River on the west to the head of the Yanert River on the east. It has been examined in most detail in the tract east and west of the Alaska Railroad, in the vicinity of Windy station. In that area it consists principally of coarse sediments that grade from conglomerate containing pebbles 6 inches or more in diameter to finer grits and sandstones, with lesser amounts of dark shale. The rocks are thoroughly indurated and in places are altered into stretched conglomerates and schistose phases. No precise measurements of the thickness of this formation have been made, but estimates indicate that in places it is as much as several thousand feet thick. Fossils are extremely rare, and such as have been found do not appear to be adequate for a close determination of the age of the rocks in which they occur. The fossils that have been identified appear to be of Eocene age, but the geologists who are most familiar with these rocks in the field are inclined to question the applicability of this determination to the entire mass of the formation and believe that at least some of it may be as old as Upper Cretaceous. In the absence of definite evidence to the contrary, however, it seems obligatory to accept the evidence of the fossil plants and regard the formation as Eocene.[25a]

Along the northern flanks of the Alaska Range, but in places folded into minor basins within the range itself, are sedimentary beds that have been more or less thoroughly consolidated and in places so strongly folded that the beds stand vertical or are even overturned. These beds have not received a specific name but are usually referred to as the coal-bearing formation. In general they comprise sandstone, clay, fine conglomerate, and numerous coal beds. Their relation to the Cantwell formation is not definitely proved, but presumably they overlie it unconformably, as they are less well consolidated and seem on the whole to have been rather less deformed. Evidently these beds were deposited at a time before the Alaska Range had its present aspects and was an area of low relief and mature drainage. With the growth of the range extensive areas of these coal-bearing rocks were stripped off, so that now the beds are preserved only in areas where erosion was least intense or they were best protected. The coal beds of this formation have great economic value and are now being productively mined in the Healy River Valley (pl. 10, *B*), which furnishes the bulk of the Alaskan coal production and practically all the lignite that is used in the Territory. The age of the formation as determined from the fossil plants found in some of its beds is clearly Eocene, and in general the beds are comparable with those in the typical Kenai area, though the identification is not specific enough to allow complete correlation and the use of a single name to cover the rocks in the two districts.[25b]

The uppermost of the recognized Tertiary formations in the Alaska Range province is the Nenana gravel. This formation consists of unconsolidated or only loosely cemented material, which for the most part is well-rounded coarse gravel and subordinate lenses of sand. This formation has a thickness in places of as much as 2,000 feet. It is interpreted as the outwash of detritus from the growing Alaska Range, which began at the end of the period of deposition of the coal-bearing formation. According to Capps, this formation is locally conformable with the coal-bearing formation and presumably of similar age. This interpretation seems to the writer somewhat open to question, and he is inclined to the belief that there was a stratigraphic break between the two formations and that the Nenana gravel may be either Miocene or Pliocene, with the likelihood favoring the younger rather than the older of these series. The full areal extent of the Nenana gravel is not shown on the accompanying map (pl. 1), not only because large quantities have been removed, but also because throughout extensive tracts it has been covered by younger deposits of Pleistocene age.

The Tertiary deposits in the Koyukuk and Dall River districts occur mostly as discontinuous patches of rather small extent, which are probably remnants of a much more widespread deposit of fresh-water origin. The beds consist of clay, shale, sandstone, conglomerate, and thin seams of lignite. They have been subjected to varying degrees of deformation, so that in some places they are little consolidated and nearly flat-lying, whereas in others they have been thoroughly lithified and have been tilted with inclinations that range all the way up to the vertical. Some fresh-water invertebrates have been found as fossils in these beds, but most of the organic remains are leaves and fragments of plants. These plant remains have been identified as closely related to known Eocene species, and the formation as a whole is regarded as more or less the equivalent of the Kenai formation of Cook Inlet, although not close enough to permit the use of that formation name for it.

In addition to these more thoroughly consolidated and deformed Tertiary beds there are some younger

[25a] Since the foregoing was written Professor Chaney has made collections of fossils from the Cantwell formation in Mount McKinley National Park that furnish indisputable evidence that those beds are Upper Cretaceous. The Geological Survey has therefore abandoned the correlation of these deposits as Tertiary and accepts the Upper Cretaceous age of the Cantwell formation.

[25b] In 1936 an expedition in charge of Dr. E. M. Schlaikjer, of the American Museum of Natural History, discovered fish remains in the valley of Healy Creek in beds toward the base of the Tertiary deposits occurring there. These fossils are of special interest as they are the first fragments of pre-Pleistocene vertebrates reported from Alaska. Plant fossils that were found in close association with the fish remains have been identified by R. W. Brown as Eocene, but Dr. Schlaikjer is inclined to favor assignment of the fish to the Miocene, even though they come from beds no younger than those containing the plants.

beds which are regarded as members of that system. Deposits of this sort have been studied especially in the vicinity of the Yukon River near Minook Creek, where they form notable terraces whose surfaces stand nearly 1,000 feet above the present-day streams. These deposits are interpreted as marking the former courses of the main drainage lines of that earlier day and are believed to be of Pliocene age. In the absence of paleontologic evidence, however, this age assignment can be regarded as tentative only. The deposits, though broadly uplifted to their present height, have not been folded or otherwise notably distorted, so they evidently were subjected to movements of great areal extent that were not narrowly restricted.

In the Eagle and Fortymile districts certain of the Tertiary rocks have not been satisfactorily differentiated from those of Upper Cretaceous age, so that the exact separation of the two systems cannot now be made and the entire sequence has been indicated on the map (pl. 1) as Tertiary. These rocks occupy a belt about 85 miles long and in places as much as 15 miles wide. They consist dominantly of sandstone and shale, with some conglomerate beds ranging from coarse bouldery accumulations to fine grit and, locally, a number of lignite beds. About 3,000 feet of beds are involved in this sequence, and the rocks are in places deformed so that their dips are as high as 70°. The fossils collected from different parts of this sequence have been identified in part as Upper Cretaceous and in part as Tertiary. Possibly this indicates that there was no stratigraphic break at the end of Cretaceous time but instead uninterrupted sedimentation into the Eocene. In that case the Tertiary beds would be somewhat older than the Kenai beds with which they have usually been correlated, as those beds are regarded as dominantly late Eocene.

In this same general area adjacent to the international boundary, especially along the Fortymile River, there are numerous high terraces and gravel deposits that appear comparable with those in the vicinity of the Yukon near Minook Creek, already described. If that correlation is valid these deposits are probably Pliocene, though there is no direct evidence available that would preclude their assignment to the Quaternary. In view of this uncertainty, it has seemed unwarranted to go further than to suggest that they may mark old drainage lines of streams that may have flowed in that region in late Tertiary time and that subsequently the country has been broadly uplifted, so that the deposits and terraces stand at considerable elevations above the existing streams.

NORTHERN ALASKA

So much of northern Alaska has not yet been explored even in a cursory manner that the distribution of Tertiary rocks in that region is more a matter of conjecture than of definite knowledge. Even with the meager information now available, however, it has been determined that Tertiary rocks representing widely different types of deposits and formed at widely different ages during that period are represented there. There are three principal sites at which Tertiary deposits have been definitely identified—namely, near the Canning River, in the Colville River Valley, and in the Kobuk River Valley. Probably the beds found at the first two sites are part of a widely distributed sequence of like deposits of marine origin throughout the coastal plain of northern Alaska, and the occurrences in the Kobuk Valley seem to be small remnants of a once extensive series of beds laid down under land conditions.

The rocks of the Tertiary occurrences near the Canning River are described by Leffingwell as neutral-tinted soft shales associated with a few bands of harder sandy shales and some layers in which occur rounded concretions a few feet in diameter. The beds break down quickly under the influence of weathering and so are rather inconspicuous in the landscape. The total thickness of the sections of beds of this type is estimated as less than 200 feet. The best exposures were found on Carter Creek, a small stream entering Camden Bay a few miles east of Collinson Point. Collections of fossils from these beds led Dall to identify them positively as Pliocene, and he stated that "the number of undoubtedly new forms precludes the fauna being regarded as Pleistocene. Moreover, the Pleistocene fauna is more Arctic in character", whereas the Pliocene fossils "indicate a temperature similar to that of the present Aleutian Islands."

The first recognition of Tertiary beds in the Colville River Valley, and indeed in the entire northern Alaska region north of latitude 69°, was made by Schrader, who noted the discovery of beds of this age in the bluffs cut by the Colville River on its western bank about 1 mile north of latitude 70°. These exposures disclosed the upper part of what Schrader called the Colville "series." This assemblage was described as being practically free from indurated rocks and consisting of nearly horizontally stratified beds of fine gray, slate-colored, or ash-colored calcareous silts containing fossil remains. These beds he regarded as being separated from both the underlying and the overlying formations by slight unconformities. No accurate measurement of the thickness of this formation was made, but from the descriptions it is obviously rather thin and may perhaps be only 100 feet or so thick. Its age is definitely determined as Pliocene, not only by its general stratigraphic relations but also from the fossils it contains, which were identified by Dall.

In beds about 50 miles west of the Colville River locality, near the head of the Topogoruk River, fossils were found which were provisionally identified as "probably Pliocene." Inasmuch, however, as definitely determined Pleistocene fossils were collected from beds that were regarded as identical with these, the presence of Tertiary rocks there cannot be accepted as demonstrated. The find, however, is of interest as indicating that such rocks may occur there and may be definitely distinguished when the area is examined more thoroughly.

The Tertiary rocks in the Kobuk Valley occur as more or less discontinuous patches, most of which are not more than a few miles in extent. One of these areas is the group of low hills between the Ambler and Kobuk Rivers, extending into the valley of the Redstone. Another area occurs on the north side of the Kobuk near the mouth of the Hunt River. The westernmost of these areas is along the north and west side of the Kobuk near the mouth of the Kallarichuk River and between that stream and Trinity Creek. The Tertiary rocks in the easternmost area, between the Ambler and Kobuk Rivers, consist of conglomerate, soft cross-bedded sandstone, and shale. Many of the beds are carbonaceous and contain obscure plant remains. Near the Hunt River and at the westernmost locality the beds are dominantly conglomeratic. Some coal beds occur in the section and near Trinity Creek have been mined to some extent to supply the local needs of miners in the nearby placer fields. At all these localities the beds have been thrown into folds, some of which show dips as steep as 30°. The boundaries of many of the areas are determined by faults along which the Tertiary beds have been dropped into their present inset positions. In all the places where these rocks were examined they rest unconformably on metamorphic rocks of Paleozoic or older age. Only a few fossils have been collected from any of these beds, but they have all been identified as closely comparable with the forms from the upper Eocene Kenai beds. There is still some doubt as to the relations between these Tertiary rocks and those of Upper Cretaceous age. Many bits of evidence suggest that there was almost uninterrupted deposition from Upper Cretaceous into Tertiary time. According to this interpretation, the Tertiary beds may mark deposits formed close to the shore or on land at a late stage in the constantly encroaching invasion which began in the Upper Cretaceous and was brought to an end by the mountain building that took place in the Tertiary.

SEWARD PENINSULA

Along the shore of much of Seward Peninsula is a coastal plain of varying width, which was formed beneath the sea and uplifted in relatively recent time. Near Nome ancient rich gold-bearing beaches occur in the deposits of this plain, and consequently considerable underground excavations have been made in them in the course of mining. In some of these excavations that reach down to the lower beds fossils of marine animals have been discovered, which were identified by Dall as Pliocene. The examinations of these strata have not been sufficiently detailed to permit distinguishing the beds of Tertiary age from the others, which presumably are younger. In fact, some doubt has been expressed as to the validity of the Tertiary determination, because of the apparent youthful character of the sequence as a whole. This doubt seems hardly justified, because the general stratigraphic succession confirms the paleontologic evidence to the extent of showing that the fossils occur only in the older beds. If, then, this identification is accepted, it indicates that in this locality at least there are relatively thin beds of marine sand and gravel that were laid down in Tertiary time. The general similarity of the coastal plain in other parts of the peninsula to that at Nome leads to the belief that further examination of similar deposits in those other parts of the peninsula is extremely likely to disclose beds that are to be correlated with these late Pliocene deposits.

Tertiary sedimentary rocks that were laid down under land conditions have also been identified at a number of points in Seward Peninsula—namely, in the valley of the Sinuk River, in the western part of the peninsula; in the valley of the Kugruk River, in the northern part; and in the valley of the Koyuk River, in the southeastern part. Most of these tracts now have only a small extent, but doubtless in the past they were much larger and have been reduced through erosion or through being covered and masked by later deposits. In all these localities the beds are dominantly composed of sandstone and shale, with some coaly layers. In the locality on the Kugruk River the coal is very thick and has long been mined as a source of local fuel. All the beds have been somewhat deformed, so that in places dips of as much as 70° are by no means unusual. The paleontologic evidence as to the age of these rocks is not adequate for basing a final conclusion but is believed to indicate that the beds are Eocene and probably are in general correlative with the beds of similar composition and relation that are so widely distributed through other parts of Alaska and that have usually been referred to as Kenai.

BERING SEA AND ALEUTIAN ISLANDS

Although most of the islands of the Aleutian group, as well as several of the scattered islands in Bering Sea, are composed principally of volcanic rocks, there are numerous records of sedimentary deposits occurring on them. Unfortunately for definiteness of correlation of these sedimentary deposits, the earlier explorers more or less tacitly assumed that all relatively recent, lightly consolidated deposits showing carbonaceous material or coal beds belonged to a single definite deposit which was to be assigned to the Kenai formation, of upper Eocene age, or, as it was earlier called, "Arctic Miocene" age. While, in the main, there was some justification for this as a working hypothesis, it cannot be considered as well substantiated, especially as it is now known that elsewhere some of the beds thus correlated have proved to be Upper Cretaceous. Because of this uncertainty, as well as because at even the definitely established localities of these rocks their extent has not been traced areally, none of the localities have been indicated on the accompanying map (pl. 1), except those on Nunivak and Nelson Islands. At Cape Vancouver, which forms the western extremity of Nelson Island, Dawson [25c] noted cliffs rising 1,000 to 1,500 feet above the sea composed of sandstones and sandy shales, dipping southward at low and undulating angles. A few thin and dirty seams of coal are interlaminated with this series, and carbonaceous material is abundant in all the members. This section afforded fossil plants that were identified as comparable with the Kenai flora. Similar rocks are also reported on Nunivak Island, where beds of coal are said to have been mined for fuel to supply local needs.

Among the islands of the Aleutian chain on which Dall [26] mentioned indications that he interpreted as showing the presence of sedimentary Tertiary rocks, are Akun, Unalaska, Umnak, Atka, Amchitka, Kiska, and Little Kiska Islands. He did not, however, recognize these rocks on Attu, the westernmost island of the Aleutian chain, though both he and Dawson [27] reported that they occurred on the Commander Islands, which form the continuation of that chain off the Siberian coast.

On St. Paul Island, which is one of the Pribilof group, at a locality known as Black Bluff, Dall reported the outcrop of "horizontal layers of a hard claystone with others in which lime predominates, forming a pale-gray fine-grained clayey limestone, or in which a conglomerate of pebbles of volcanic origin is bound together by a limy matrix." About 28 species of marine fossils have been identified from these beds, which Dall regarded as Tertiary. Dawson, however, reviewing Dall's conclusions in the light of additional information obtained by J. Stanley Brown, concluded that the fossils were merely in detached fragments of calcareous argillite that had been torn from their parent beds, now under the sea, by the volcanic eruptions and built into more recent deposits then in course of formation. Such an interpretation would therefore assign these beds to post-Tertiary time but would still admit the presence nearby of Tertiary rocks from which these fragments with their fossils were derived. A test as to the validity of either interpretation can be made only through additional field evidence.

None of the other islands of the Pribilof group, nor St. Matthew or Hall Islands, to the north, are known to show outcrops of the sedimentary members of the Tertiary system, though they are composed of volcanic deposits of that age. So far as known, the bedrock of St. Lawrence Island is composed of much older rocks than the Tertiary, but the reported occurrence of lignite on that island warrants speculation as to whether some small areas of Tertiary sediments may not occur there.

QUATERNARY SYSTEM

The vagueness of the events that make up ancient geologic history gives place to more and more definiteness as they approach the present day. Inasmuch as the Quaternary period includes Recent time, many of its incidents are matters of current observation rather than deductive conjecture. Obviously this greater wealth of information makes it necessary to eliminate much if its volume is to be kept within reasonable limits for so general a statement as this report aims to afford. Consequently, it must be realized at the outset that in the main the kinds of processes that are operative today have been active throughout Quaternary time. Furthermore, even at the beginning of that period the major features of the Territory had already been blocked out, so that the changes that they have experienced since are more matters of degree than of kind. In other words, throughout the Quaternary period, which may have so far embraced a million years or so, winds have blown across the country, water has fallen as rain or snow, weathering has proceeded under normal changes of temperature and moisture, seas have beat on the coasts and modified them, streams have flowed down the slopes, carving here and depositing there, and deep-seated forces have produced modifications through their potent but slow-acting might or, through volcanic activity, created stupendous monuments by their unleashed action.

In thus emphasizing the general uniformity of geologic processes that have been operative in Alaska in Quaternary time, that statement should not be construed as indicating an undeviating similarity to present conditions. It is well known that in parts of the Territory some of the present land has been under the sea at earlier times during that period, and other parts that were once submerged have become dry land, as is clearly illustrated by the coastal plains found at intervals in many parts of the Territory, among which that near Barrow furnishes an excellent example (pl. 11, *B*). At times during the Quaternary the climate has been far different from that of the present and so has allowed the local accumulation of more extensive snow and ice fields. Rivers have carved new valleys or have

[25c] Dawson, G. M., Geological notes on some of the coasts and islands of Bering Sea and vicinity: Geol. Soc. America Bull., vol. 5, pp. 117–146, 1894.

[26] Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey, 17th Ann. Rept., pt. 1, pp. 811–814, 1896.

[27] Dawson, G. M., op. cit., pp. 123–127.

been diverted from former courses, and have deposited or removed vast quantities of material from their drainage basins. But, although there have been constant changes in progress, which in the aggregate have altered profoundly the aspects of certain parts of the country, those changes have been in general uniform in kind with those that are going on today.

In order to avoid loading this record with details, it has been considered best to single out two or three of the features of the Quaternary that deviate most widely from those that prevail at present and to pass over those that vary less notably. Furthermore, the representation of the members of the Quaternary system on the accompanying map (pl. 1) has been restricted to those areas where the deposits of that age have most conspicuous development. If such a restriction had not been adopted, the map would show only the appropriate Quaternary symbol, because every hillside is covered with the accumulation of weathered material formed during that period, the entire coastal province has marine deposits near shore, and near every stream are the sands, silts, and muds transported by it during stages of high water.

In selecting the few especially significant examples of the Quaternary deposits for particular mention, weight has been given to those concerning which the most definite information is now available. It has therefore been necessary to omit discussion of many interesting and important subjects, such as the scattered records available as to Quaternary movements of the land with respect to the sea, in spite of the fact that Quaternary uplifts amounting to thousands of feet have been identified locally and that scores of records indicating uplifts of 100 feet or more are common. Only four special subjects bearing on the Quaternary history will therefore be discussed in this paper—namely, the glacial history of the region, the frozen-ground deposits, the mineral placers, and the volcanoes. The first three are described in the immediately following pages and the fourth in the section dealing with the Tertiary and younger effusives (pp. 79–86).

GLACIATION[27a]

At the present time glaciers cover an area roughly equivalent to less than 4 percent of the area of the Territory. These glaciers range in size from small tongues of ice extending only a short distance beyond the snow banks at their heads to majestic streams tens of miles long and a mile or more in width (pl. 13, *B*), or stagnant piedmont fields embracing, as in the Malaspina Glacier, an area of ice roughly 50 by 25 miles. Most of these glaciers wither away and end on the land at elevations where melting is faster than the accession of ice, but scores of them extend all the way to the coast and enter the ocean waters. Among the unforgettable memories of a lifetime is the sight of the towering ice fronts of some of the larger of these tidal glaciers, rising hundreds of feet above the sea and displaying a range of colors from the spotless white of snow through sea greens and all shades of blue to the deepest ultramarine. No less impressive are the torrential streams issuing from many of the glaciers that end on land and that transport heavy boulders along their beds hidden in the rushing milky silt-laden waters. The present extent of the glaciers, so far as is consistent with the scale, is shown on plate 12 by distinctive symbols. It is evident that by far the larger number, and those of greatest volume, are situated in the southern mountain areas, especially the Coast, St. Elias, Chugach, Wrangell, and Kenai Ranges.

The second most extensive glacial area is in the Alaska Range, from the vicinity of Mentasta Pass westward through the great arc that passes through Mount McKinley and then southwestward nearly to Lake Iliamna. A few small glaciers occur in other highland areas, but it is a noticeable fact that in the Brooks Range, in northern Alaska, which forms the divide separating the streams flowing southward into the Yukon and nearby valleys from those flowing northward into the Arctic Ocean, glaciers are practically nonexistent. This apparently anomalous fact that the farther north one goes in Alaska the less glaciation he finds, can be readily understood when the difference in amount of precipitation in the two regions is realized. Thus in the vicinity of Cordova the mean annual precipitation is approximately 150 inches, whereas at Barrow it is less than 6 inches. Although it is probable that in the mountains near these settlements the precipitation may differ somewhat from the figures stated, it nevertheless is a fact that there is a tremendous difference in the precipitation in the two areas. In other words, in the southern area there is an abundance of precipitation, much of which falls in the form of snow, to support glaciation, whereas in the northern area the precipitation is not sufficient to do so. Adequate precipitation in the form of snow is a far more potent factor than low temperature in forming and sustaining glaciers.

The fronts of the present-day glaciers are not stationary but are constantly altering through the accession of more ice from the headward parts or through wasting away by melting or the breaking off of blocks that are undercut by streams or the sea. As a consequence, at times some of the glaciers are receding at varying rates, and at other times or places they are advancing. As a whole the glaciers of Alaska are now receding and thus laying bare country that only a few years ago, within historic time, was ice-covered. A striking example of this sort is in the Glacier Bay Monument, in southeastern Alaska, where the retreat

[27a] The basal facts on which the following statements rest have been taken principally from the summary report by S. R. Capps, Glaciation in Alaska: U. S. Geol. Survey Prof. Paper 170, pp. 1–8, 1932.

of the Grand Pacific Glacier (pl. 13, *A*) for several miles since the boundary between Canada and the United States was established has opened a deep waterway into part of Canada that was formerly closed by a barrier of ice.

In addition to these smaller changes that are occurring from day to day and from year to year, there have been in the past much greater expansions of the glaciers of Alaska. That this should have occurred does not seem strange when it is remembered that in the early part of the Quaternary period practically all of Canada was covered by an enormous ice sheet whose southern border extended into the United States, in places as far south as the latitude of southern New York and Pennsylvania. In Alaska, no such area was covered by a vast sheet of ice, such glaciers as were formed centered in the mountain masses and radiated outward from them along the courses of the already established drainage lines until, reaching broad lowlands or the sea, they deployed and coalesced as piedmont lobes. The maximum extent of these old glaciers is graphically shown by plate 12, from which it will be apparent that practically the entire central part of the Territory was free of ice at that time and was doubtless an area in which many forms of life that were driven from their former habitats by the advancing glaciers found refuge and an abiding place. This central area, however, was not immune from the effects of the expanding glaciers, because the rock waste scoured from their beds and the material transported by them was dumped near their fronts or spread out over parts of the ice-free area by the water formed through their melting. Thus many of the present-day deposits in that area still preserve the evidences of those processes.

Within the area once occupied by the ice the evidences of that event become increasingly striking inward from the margins toward the old centers of ice dispersal. These evidences consist of glacially sculptured valleys and hill slopes and scattered deposits dropped directly by the ice itself or fanned out by the streams that had their sources in the waning glaciers. Much of the splendor of present-day Alaskan scenery is directly due to the glacial history that the surface has passed through. The magnificent Inland Passage through southeastern Alaska follows in the main fjords that in part at least have been scoured out by glaciers that flowed down the old drainage lines and formed the present astonishing network of waterways. The mountains that tower majestically above these channels show by their rocky oversteepened slopes the work of those now-vanished ice streams. The numerous waterfalls and sites along that route at which power can be profitably developed when needed also bear silent testimony to the potency of the processes, mainly glacial, that created them. Elsewhere in Alaska the signs of the former glaciation of the area are equally obvious. Hundreds of rocky basins, now filled with lakes, have been excavated by the old glaciers. Perhaps the most striking examples of this type of lake are those that flank the hills north of Nushagak, where there are a dozen or so lakes of this sort, some as much as 35 miles long and more than 900 feet deep. But it was not alone the excavating action of the old glaciers that produced some of the present forms, because they also deposited in characteristic manner the load of land waste they had accumulated. These deposits are distinctly different from those produced by other agencies in that they have undergone little sorting, and the fragments are normally rough and angular and have not been rolled, like the materials carried by rivers or the sea. Then too the glaciers usually laid down this material in irregularly distributed forms that produce a hummocky topography—scattered mounds being interspersed among depressions, many of which are partly filled by small lakes and ponds. Naturally, many of the present land forms are produced through a combination of processes, together with glaciation, so that products of glaciofluviatile, glaciolacustrine, and glaciomarine action are perhaps even more common than those that have been formed by any single agency and partake of features that include the composite aspects of all the processes involved in their formation.

Alaska affords a particularly good opportunity for the study of past glacial conditions, not only because many of the ice masses can be traced with considerable continuity from their present to their once expanded state but also because in many places the actual limits of that expansion are clearly shown. Thus, the former glaciers that extended north from the Alaska Range and both north and south from the Brooks Range terminated on land, and so their limits can be critically examined in as much detail as desired. In addition, certain small mountain groups that bore local glaciers during the time of maximum glaciation give supplementary evidence as to the ice movements in different directions and also show that practically all highlands standing as much as 4,000 feet above the sea were capable of originating local glaciers at that time and most of them did so.

So recent are some of these glacial deposits that even vegetation has not yet had time to gain a foothold on them. In fact, it is impossible in many places to draw a distinction between these old glaciers and the present-day ones that are the shrunken remnants of those formerly more majestic ice streams. By this statement it is not intended to imply that successive steps in the recession of the ice sheets cannot be recognized, because evidences of temporary halts in that recession are discernible everywhere within the formerly glaciated area. Nor was this general recession of the ice from its outermost limits progressively in one direction only. Like the present glaciers, these

A. MOUNTAINS AND GLACIERS OF GLACIER BAY NEAR THE INTERNATIONAL BOUNDARY, INCLUDING MOUNT FAIRWEATHER AND GRAND PACIFIC GLACIER.

B. TWIN GLACIER AND MOUNTAINS OF THE COAST RANGE ADJACENT TO TAKU ARM EAST OF JUNEAU old glaciers undoubtedly advanced at intervals during the general period of recession, reencroaching on country that they had left. In other words, the ice fronts of that time were in the same fluctuating condition as those of the present glaciers—an unusually heavy accretion of snow being followed in due time by advances and an excess of melting over accumulation being followed by retreat.

Evidence as to the exact correlation of the great extension of ice in Alaska with the similar phenomena in Canada and the United States is still inconclusive. Capps, from his investigations, reached the conclusion that the last great ice advance in Alaska was essentially contemporaneous with the Wisconsin stage of glaciation in the northern United States. In support of this belief he called attention to the uneroded character of the morainal deposits, which still show kettle and hummock topography, little modified by erosion; the abundance of polished and striated rock surfaces and erratic boulders in areas where weathering is rapid; and the general unoxidized character of the glacial till. He also gave illuminating and ingenious inferences from certain ring counts of trees in the White River region by which the indefinite geologic age determinations can be roughly transformed into units of years. From these facts Capps concluded that the time since the maximum extent of ice in the White River Valley is of the same order of magnitude as the 30,000 to 60,000 years which, according to the general consensus of opinion, is the time since the Wisconsin continental ice sheet in the States began its retreat.

Much more corroborative evidence must be obtained before the maximum glaciation in Alaska can be definitely dated. On purely theoretical grounds it seems possible that glaciation in the States and glaciation in Alaska were not coincident and might even have been in such mutual adjustment that the maximum extent in one area coincided closely with a lessened extent in the other. Such a condition could readily be imagined to follow on the growth and decline of the mountains bordering the northern Pacific Ocean, whereby the moisture-laden winds from the west were forced to lose part of their moisture content in the mountains when they stood high and could pass inland with less obstruction and loss when they were low. No specific evidence of such relations has been found, though it is known that since late Tertiary or more probably early Pleistocene time parts of the St. Elias Range have undergone uplifts of at least 5,000 feet. The consequences of such profound topographic and climatic changes are matters that can only be regarded as of speculative interest until more specific facts become available through close field observation of the varied lines of evidence that may be traced out.

As is well known, the ice age in the United States and Canada did not consist of a single great ice advance followed by recession to the recent conditions but was composed of several stages of advance and retreat. At present five such ice advances are generally recognized in the States, separated by four interglacial stages in which the ice retreated and almost entirely or largely disappeared. It is a matter of some interest, therefore, to examine the Alaska record to see whether similar fluctuations have been recognized in the glacial features and deposits that are preserved there. No comprehensive investigations of this subject have yet been made, and the conditions for disclosing the evidence bearing on it are too poor to allow any satisfactory answer to this question as yet.

There are, however, several scattered bits of evidence which suggest that there have been such glacial and interglacial stages, though their number, extent, and correlation are entirely undetermined. Capps mentions four places where indications of such earlier stages of Quaternary ice advance have been reported—namely, in the vicinity of Mount St. Elias, in the White River Valley, in the Nenana Valley, and in the Mulchatna Valley. The three localities last named are all on the northern or northwestern flanks of the Alaska Range. The occurrence near Mount St. Elias has already been mentioned in discussing Russell's Pinnacle "system" of the Tertiary or Quaternary in that area. The age of this sequence of rocks is by no means definitely determined and so far as is now known may be either late Tertiary or Pleistocene. These beds are identified by both Russell and Maddren as being unquestionably of glacial origin, in part at least, but it is by no means proved that even if they are of Pleistocene age they have other than local extent, and they may as well have been laid down during a time when only a small part of the country was ice-covered as at a time of great ice expansion.

In the White River Valley 10 distinct beds of tillite separated by glaciofluviatile deposits of sand and gravel, the whole section somewhat tilted, were overridden and smoothed by the later ice advance. The precise age of these old till and gravel deposits is not known, though it certainly antedates the last great ice advance. Thus, although Capps assigns these beds to the Pleistocene, they afford no basis for going much further than to conclude that they constitute a record of glacial conditions in that part of Alaska at some time long before the last great ice expansion.

In the Nenana Valley Capps found erratic blocks at elevations of more than 2,500 feet above the river and 25 miles beyond the limits of the moraines that mark the front of the supposed Wisconsin glaciation. The amount of weathering that these erratics have undergone suggests that they are more likely to belong to a late pre-Wisconsin stage than to an early one. In the Mulchatna Valley Capps found a deposit of deeply oxidized and weathered material that he interpreted as part of an old glacial moraine. This material is overlain by several hundred feet of fresh, unoxidized glacial till that forms a lateral moraine left by the last great advance of the ice in that part of Alaska. Unquestionably the underlying material was formed during an expanded stage of the ice in Pleistocene time, though it cannot yet be identified as belonging to any specified stage. Possibly this old morainic member is to be correlated with the material observed by the writer in the Stony River Basin of the Kuskokwim Valley. At that place, on the northern slopes of the Lime Hills, morainic material was recognized at an elevation of 1,200 feet, or 600 to 800 feet above the water in the Stony River. The glacial character of this deposit was especially evident from the many angular boulders of porphyritic granite, which must have come from a long distance, as no similar rocks are known in the neighborhood. These boulders are considerably decomposed and must have been exposed in their present position a long time—a much longer time than any of the other glacial deposits that were seen, if depth of decomposition and weathering is to be trusted as a valid basis for comparison.

To review what is now known of glaciation in Alaska, three facts seem to stand out as especially noteworthy. (1) Glaciation in Alaska was not restricted to the Pleistocene epoch but has been more or less continuous throughout the Quaternary period down to the present day. (2) Although there was a great expansion of ice in Pleistocene time, that expansion was by no means so surprising as the fact that so large a part of the region now lying within the Arctic and subarctic portions of the Territory was ice free when such extensive areas in the temperate regions of the States were overwhelmed by an ice mass of continental dimensions. (3) In the main the present as well as the past glaciation has centered in the mountain areas, and the ice has moved outward from those highlands and occupied the already established lines of flow that had been carved by rivers and other agencies.

PERMANENTLY FROZEN GROUND

One of the curious phenomena that attracted considerable interest of the earlier travelers to the Territory, as well as of later comers, is the presence of ice and frozen ground near the surface at many places in central and northern Alaska. This feature is not unique, for millions of square miles in the Northern Hemisphere, both on this continent and in Asia, reveal similar conditions. Broadly speaking, the permanently frozen ground in Alaska may be considered as forming a layer having an areal extent measured in thousands of square miles and a thickness in places of hundreds of feet. The upper limit of this layer is determined by the surface of the country and the depth below that surface to which seasonal melting takes place—usually a matter of a very few feet where the surface mat of vegetation is unbroken. Its lower limit is controlled by a complex relation between several factors, of which one of the most influential is the upward migration of heat from the earth's interior. Necessarily, these limiting surfaces are irregular in form and constantly subject to fluctuations in position. This layer obviously embraces all kinds of earth materials—solid rocks, deposits of sand, gravel, and soil—but as the effects of frost are most recognizable in those materials that would otherwise be loose and unconsolidated, they are the materials in which the phenomenon is most conspicuous. Altogether a considerable body of information has been gathered regarding these permanently frozen deposits, because in most of the placer-mining camps the miners have had to excavate into them to find the gold-bearing layers they were seeking. The available record as to the distribution of permanent frost is far from complete, but from such data as are at hand the accompanying sketch map (pl. 14) has been prepared to show the places where it has been definitely recognized. In interpreting this map the reader should realize that the forms of symbols have been conventionalized so that they do not cover all of the area occupied by the permanently frozen ground. Thus, in Seward Peninsula only nine symbols have been shown, centering at the nine most important mining camps, though if the writer had indicated all the places in the peninsula where permanently frozen ground is known, he would have included practically the entire peninsula. A similar statement would apply to practically all the area between the Yukon and Tanana Rivers and almost all the country north of the Arctic Circle.

Probably the most striking of the deposits within the area of permanently frozen ground, not only in Alaska but throughout the Northern Hemisphere, are the masses of clear ice of all sizes, shapes, and distribution. In many places the general way in which these masses occur resembles the diverse forms in which intrusive igneous rocks intersect the country rock in all directions as dikes, sills, and stocks, except that instead of traversing the hard rocks these masses occur in the frozen silts and sands.

The origin of these ice deposits, as well as of the frozen layer in general, presents many problems which have not yet been satisfactorily solved. For a long time it was generally assumed that they were more or less relics of the ice age and that the ice masses were, in part at least, the buried remnants of the ice sheets of that time. This view has now been entirely abandoned as an explanation of the known deposits, because it does not fit the demonstrated facts. In the first place, these ice masses and frozen ground lie far outside the limits reached by those old ice sheets, and many of them cut across deposits formed subsequent to the time when the glaciers had their greatest extent. As indicating a probable relation between the distribution of the permanently frozen ground and present-day temperature, attention is invited to plate 14, showing the general distribution of known permanently frozen ground. This illustration is based on incomplete information, but it is believed that the general absence of symbols in the area south of latitude 60° is really significant and indicates that except in the higher inaccessible mountains permanent frost is largely absent from the unconsolidated deposits. In other words, a line indicating the approximate southern boundary of permanent frost in the unconsolidated deposits would, it is believed, pass very close to the indicated symbols. Although such a line has not been shown on the map, it is significant to compare its imaginary position with the indicated isothermal line for the mean annual temperature of 30° as determined by the Weather Bureau [28] from its available records.

From such a comparison it will be apparent that on the whole the coincidence of the two is so close that only two of the symbols indicating frozen ground fall in the zone of higher temperature south of the 30° isotherm. Undoubtedly the data from which the isotherm was constructed, like those on which the symbols of frozen ground are based, were incomplete, so that neither can be relied on as to matters of detail. They do, however, approximate each other so closely as to justify the belief that they have a mutual interrelation. In other words, it is reasonable to believe that conditions of permanently frozen ground would naturally be induced in those areas where the mean annual temperature is below 30°, or approximately the freezing point of water. Consequently, it is entirely reasonable to infer that little if any change in the climatic conditions of the present time is required to account for the formation of those permanently frozen deposits in the past and their preservation today.

The preservation of many of the records of the geologic past under this natural refrigeration enables the reconstruction of many incidents and events of which evidence would otherwise have become obliterated or destroyed. Particularly fortunate has been the preservation of many remains of the animals and plants that formerly flourished in this region. An enormous quantity of bones of animals such as the mammoth, mastodon, musk ox, and bison, which are now extinct in Alaska, as well as of many other animals, the descendants of which still live in the Territory, has been found in these deposits. Hardly any extensive tract of the permanently frozen ground is opened up that does not disclose some of these remains. So well preserved are some of these fossils that even specimens of the sinew, hair, and marrow have been collected. The droppings of ratlike animals and even their trails to their nests are abundant in some of the frozen silt or muck deposits near Fairbanks. Plants, too, contributed to the bulk of these deposits, and old beds of peat, shrubs, and trees, some still erect and with their roots preserved in place, are disclosed in many of the sections. Even a layman wandering among extensive openings on these deposits cannot but be thrilled as mentally he is carried back to the vanished past, when these animals were living and the events chronicled by these deposits were vital current happenings.

[28] Day, P. C., Summary of the climatological data from Alaska, by sections: U. S. Weather Bureau Bull. W, vol. 3, 1926.

PLACERS

In no other single way are the Quaternary deposits of Alaska of more general significance than through the fact that, in the main, they are the deposits from which the large amounts of placer gold was recovered that fired popular interest in the Territory and still yield millions of dollars annually to the fortunate miners. As is well known, the formation of commercial placers depends on the presence of a mineralized area of bedrock that has been subjected to weathering processes whereby the parent rock is disintegrated so that the fragments or particles are subjected to movement in which some sorting with respect to the different physical properties of each is effected. In the case of gold placers, the gold that was originally present in the veins or mineralized material is extremely heavy in comparison with similar sized particles of any of the minerals with which it is commonly associated. Furthermore, it is practically unaffected by any of the common earth solvents, which will attack other minerals. As a result, when disintegrated rock material containing gold is subjected to sorting by wind, running water, currents of water along the sea or lakes, or even by downhill creep, the gold tends to lag behind the other material and thus be concentrated, while the lighter material tends to be carried away. The more effective the concentration, other things being equal, the more likely is the resulting deposit to be worth mining. Not only may such concentration be the result of a single process during a more or less limited time, but it may be repeated again and again. As a result placers may be formed under a great variety of conditions and bear strikingly different relations to the present topography. So many classes or types might be distinguished, and so great a range of imperceptible gradations between them might be drawn, that each deposit may be regarded as distinct from all others. In the main, however, two principal divisions of placers are recognized, in one of which the material has collected near the site of the bedrock mineralization practically without any transportation other than gravity being involved, and in the other the concentration has been effected through transportation mainly by water sorting. Examples of the first class, or residual placers, are of relatively little economic importance compared with those of the water-sorted type. In the second class various subdivisions may be made, dependent on the kind of water involved in the transportation, but the two principal ones are those formed by streams and those formed along beaches of the sea or of lakes. Examples of the stream placers are found in practically every placer camp in the Territory. The best examples of beach placers are the famous beach at Nome, the less well-known beaches at other points in Seward Peninsula, and the beaches swept by the Pacific Ocean from Lituya Bay to and beyond Yakataga. Other subdivisions of each of these major classes are based on the relations of the deposits to the present stand of the land, because some of the older ones have been formed at an earlier time, when the land stood higher or lower, and thus are now buried beneath later deposits or occur high on the hillsides far above the present streams or seas. Beaches 100 feet or more above the present sea level and others considerably below that level are recognized at Nome, and some of them have yielded millions of dollars' worth of gold. Old channels, high above or far below the present streams, are common in parts of Seward Peninsula (pl. 11, *A*) and the whole central Alaska region (pl. 10, *A*) and thus shed light on the Quaternary history of those parts of Alaska in which they occur.

Contrary to some popular opinion, few if any of the productive placers have been formed through the direct agency of glaciation. On the whole the effect of glaciers is to move such material as is ice-transported without much sorting action and to scour bodily away such material as they override and disperse any concentration that may have previously been produced in it. As a result most of the areas in Alaska that have been strongly glaciated contain few productive placers, and search for such deposits in those areas is seldom rewarded by success. However, although the direct effect of glaciers is such as to destroy or prevent the formation of productive placers, their indirect effect may be quite the reverse. Thus, the great dumps of material scoured and transported by glaciers, or by the streams issuing from them, are in such condition that if re-handled by some sorting agency, such as running water, any gold contained in them may be concentrated and thus form workable placers. Some of the placer fields in the mountain areas owe their existence to such a combination of processes. As examples of the type of deposits formed through re-sorting of material in part of glaciofluviatile origin may be cited the productive camps in the Nizina, Chistochina, and Valdez Creek districts.

The whole subject of placer formation is so complex that to describe in any detail the known Alaskan occurrences would require long separate treatment by itself. The subject is referred to only briefly in this report as illustrating one of the interesting and important items connected with the general Quaternary history of Alaska. Obviously the unraveling of the various episodes in that history is not only of theoretical significance but can be turned into direct financial returns by focusing attention on areas where such placers are likely to occur and thus avoiding unprofitable expenditure of time, money, and labor in less promising areas. The applications of the investigative methods of geology to the solution of the problems raised by such prospecting are almost limitless.

IGNEOUS ROCKS

So far in this report attention has been directed almost exclusively to the deposits formed by fragmentary material that has been laid down through water action and later more or less consolidated into the so-called sedimentary rocks. There is, however, another large and in many respects more important class, which includes rocks that have been formed by the cooling and consolidation of once molten rock that originated deep underground—the igneous rocks. Some of these rocks cooled and consolidated beneath the surface and now appear at the surface only because the cover of rocks that once concealed them has been worn away. Others burst through the overlying cover and were poured out as sheets of lava on the surface, or formed volcanic vents with the accompanying characteristic cones, lava flows, and ash and ejected material. Each of these types has certain distinctive features which permit the geologist to differentiate between them in many places, though in some places there is such a gradation between them that no sharp line can be drawn. In general the rocks that have cooled slowly under considerable cover are coarser grained, and the individual mineral components have crystallized out completely, as in granites or diorites. The rocks that have cooled quickly have finer grain, and many of the minerals have not had time to form good crystals, and that material has chilled into a glass. In an extreme example of that sort, such as obsidian, the rock is completely glass, and a more common type is basalt. Different parts of the same mass may cool at different rates, so that in a single thick lava flow the margins may be glassy, whereas the inner parts may be crystalline and coarser-grained. The original chemical composition of the molten material is also an important factor in the way that cooling proceeds, the highly acidic or quartzose material chilling quickly as compared with the highly basic or iron-bearing kind. The appearance and quality of the resulting rocks depend on their chemical composition, mode of formation, and numerous other factors, so that many names have been given to the different kinds of igneous rocks to designate some of these differences. In fact, the nomenclature of igneous rocks has become so highly specialized and technical that for a report such as this one, which aims to give only general information, many of these distinctions have had to be disregarded.

The reader desiring more exact discrimination of the various igneous rocks of Alaska should therefore have recourse to the more detailed reports on the different districts. For the purposes of this report only two main classes of igneous rocks have been differentiated—namely, intrusive and volcanic. By the use of these terms convenient and not too precise labels are made available for describing the general features of the igneous rocks of the Territory. As used here it is intended to restrict the term "intrusive rocks" to those that were intruded into the crust of the earth and in the main consolidated within that crust. The term "volcanic rocks" is here applied to all other kinds of igneous rocks but embraces mainly the sheets of lava poured out at the surface, or the material blown out and more or less comminuted by the explosive action through which it was expelled from within the earth's crust. The inexactness of the foregoing distinctions is especially apparent in the case of the so-called volcanic type, because obviously in part of the journey of this molten material to the surface it traversed the preexisting country rock and was therefore to that extent "intrusive", but to avoid undesirable duplication of description such intrusive portions will not be described separately. The converse would also be true of the so-called intrusive rocks, for undoubtedly some of them are the deeper portions of igneous masses, whose upper part reached the surface and may have been poured out as lava flows. The classification adopted here is therefore to be regarded simply as reasonably useful, though by no means scientifically exact or consistent. Furthermore, in the following statements only the more generalized names of the different kinds of rocks will be used rather than the petrographically more precise names.

The stratigraphic position of some of the deposits of igneous origin, such as those composed of volcanic ejectamenta, has been mentioned in foregoing parts of this report, because those deposits were laid down as interlayered members of the ordinary sedimentary sequence. In general, however, the close dating of igneous rocks is a difficult matter, because those that solidified from molten material do not, of course, contain any organic remains, and almost the only definite clue as to their age lies in their relation to rocks of known age which they intrude, rest upon, or underlie. Obviously, such criteria do not allow close determination, for it is by no means probable that they cut rocks of all ages up to those formed just before the igneous intrusion took place, or that they were poured out on deposits that just preceded the outflows of lava, or that they were immediately buried by deposits whose age can be determined. For this reason on the accompanying map (pl. 1), no attempt has been made to draw as fine distinctions of age between the igneous rocks as between the sedimentary rocks. Instead only three main time groups of the so-called volcanic rocks have been shown, and all the intrusive rocks indicated are grouped together. In the following text, however, some details are given regarding the relative chronology of the different members of these groups in some of the regions.

PALEOZOIC OR OLDER VOLCANIC ROCKS

SOUTHEASTERN ALASKA

In southeastern Alaska volcanic rocks are recognized as members of each of the systems of the Paleozoic era from the Ordovician through the upper part of the Carboniferous. The areal distribution of many of these rocks is small or has not been worked out in enough detail to permit their complete representation on the accompanying map (pl. 1). As a consequence they are much more widespread than is shown by the map. The oldest of these rocks are apparently those that form part of the Wales group in the Ketchikan district. They have been considerably altered and metamorphosed, so that they are now greenstones and greenstone schists in which the original structural features have been largely destroyed and the original minerals replaced by secondary ones, these changes having been brought about largely by tectonic forces in combination with magmatic instrusions. According to Buddington, these greenstones probably represent submarine lava flows and volcanic ejectamenta collected in the old ocean of that time.

The volcanic rocks of Ordovician age are especially well represented on Kuiu and Prince of Wales Islands. At El Capitan Passage on Prince of Wales Island there is a series of volcanic rocks about 3,000 feet thick composed dominantly of andesites, which in places show structural features which suggest that they were laid down under marine conditions. At other places on that island the volcanic rocks are more or less interlaminated with shale and graywacke beds. On Kuiu Island the volcanic material is mainly in the form of tuff that has been more or less reworked by marine action. The relation of these beds to known fossiliferous strata indicates that certain of the beds at both the localities mentioned are part of the Lower Ordovician series and that others are part of the Middle Ordovician.

Somewhat above the base of the Silurian sequence, especially on Kashevarof, Prince of Wales, Kuiu, and Sumner Islands, is a series of interbedded andesitic volcanic flows and tuff which in places has a distinct "pillow" structure, as if it had consolidated under water. Numerous fragments of volcanic rocks in the

Without doubt representatives of these old volcanic rocks occur in other districts, but there they have small areal extent or are so intricately involved with other rocks that they have not been separately mapped. Thus in several areas in Seward Peninsula are greenstones that may belong to this group, though now it is impossible to determine whether or not they were originally volcanic and if so whether their age is Paleozoic. On the whole most of these greenstones in the Seward Peninsula region appear to have been intrusive, but certain of the highly feldspathic schists, such as the Casadepaga schist, may have been in part at least surface flows. None of the greenstones of Seward Peninsula have been distinguished on the accompanying map (pl. 1), but they are all limited to the areas occupied by the Paleozoic and older rocks. In the Kuskokwim Valley, a few miles east of Ohagamut, Maddren found tuffs interbedded with tuffaceous limestones and other distinctly sedimentary rocks which Harrington probably correctly correlated with the Carboniferous volcanic rocks of the Marshall district.

MESOZOIC VOLCANIC ROCKS

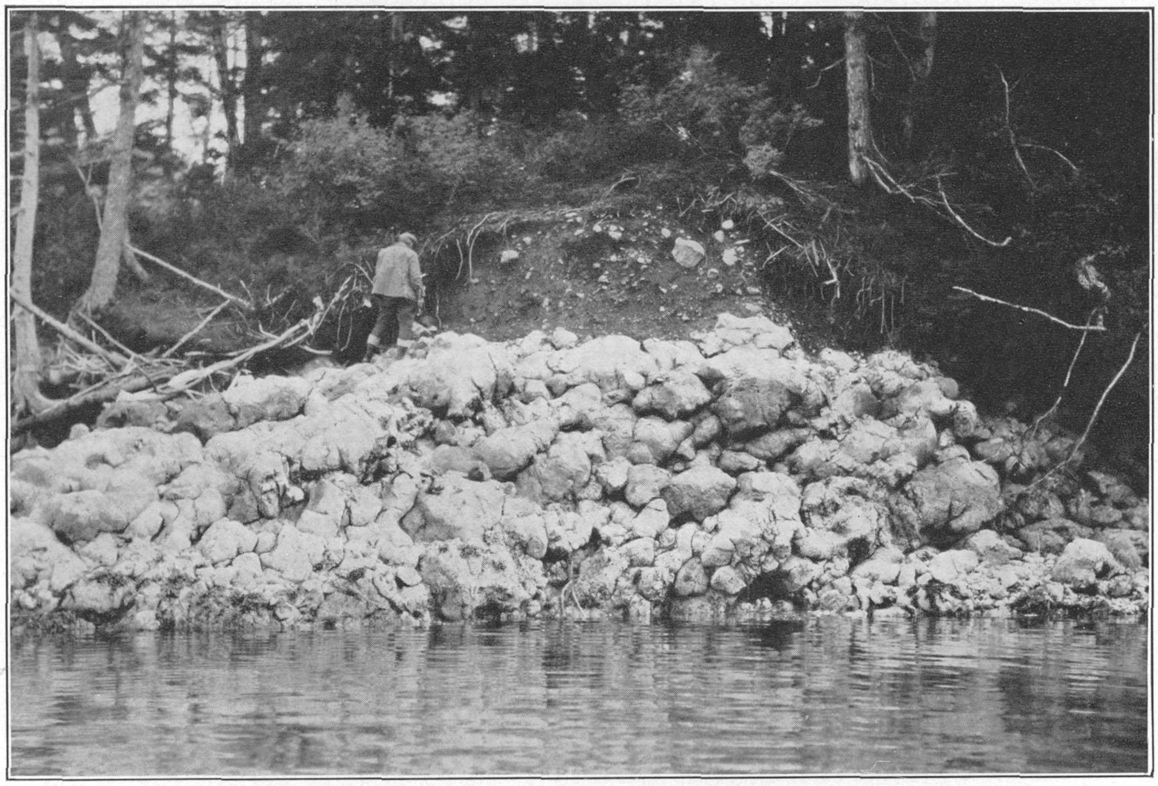
From such information as is now available it is evident that although volcanism occurred in each of the three periods of the Mesozoic era, it was much more widespread and intense during the early part of that era and gradually waned in the later part until it became almost nonexistent in the last period. In many ways this is rather astonishing, because, as discussed in the section of this report dealing with the intrusive rocks, practically a reverse condition prevailed as to the great batholithic intrusions of the coast ranges and other parts of Alaska. These deep-seated intrusions seem to have reached enormous proportions in the Jurassic and to have continued into the Cretaceous.

It is also a significant fact that the known Mesozoic volcanic rocks are practically restricted to the southern part of Alaska, notably southeastern Alaska and the area extending westward therefrom through the Copper River and Cook Inlet region into southwestern Alaska. In part this apparent restriction may be due to the unexplored condition of many parts of the Territory, but it is believed that the apparent distribution will not be greatly changed even after more thorough exploration. In other words, for some reason, which has not yet been determined, during practically the entire Mesozoic era the central and northern parts of Alaska seem to have been practically devoid of surficial volcanic phenomena that can be recognized in any of the deposits now exposed at the surface.

SOUTHEASTERN ALASKA

Volcanic rocks belonging to the Triassic, Jurassic, and Cretaceous systems have been recognized at several places in southeastern Alaska. Those of Triassic age are especially well exposed in the northern part of Kupreanof Island and the northeastern part of Kuiu Island. At those places they consist of andesitic lavas, including breccia with limestone matrix and locally interbedded with slate and other sedimentary rocks. Many of the flows show well-developed pillow structure, which is usually considered as indicating that the lavas were poured out under water. The volcanic rocks of Kuiu Island rest directly on the lower division of the Permian beds, but those of Kupreanof Island rest on the sedimentary division of the Upper Triassic. Possibly some of the volcanic agglomerates on Gravina Island are of Upper Triassic age, but it seems certain that most of them belong higher in the stratigraphic column. In the Juneau district Martin has distinguished the Gastineau volcanic group, which he considers of Upper Triassic age. The base of this group consists of andesitic lava with local lenses of slate. This is succeeded by calcareous slate carrying Upper Triassic fossils, and this in turn is overlain by andesitic tuff, over which, and forming the top of the group, are beds of slate. The correlation of the volcanic members of this group with the Triassic is admittedly open to serious question. The total thickness of the group, including both volcanic and sedimentary members, is estimated to be about 5,000 feet.

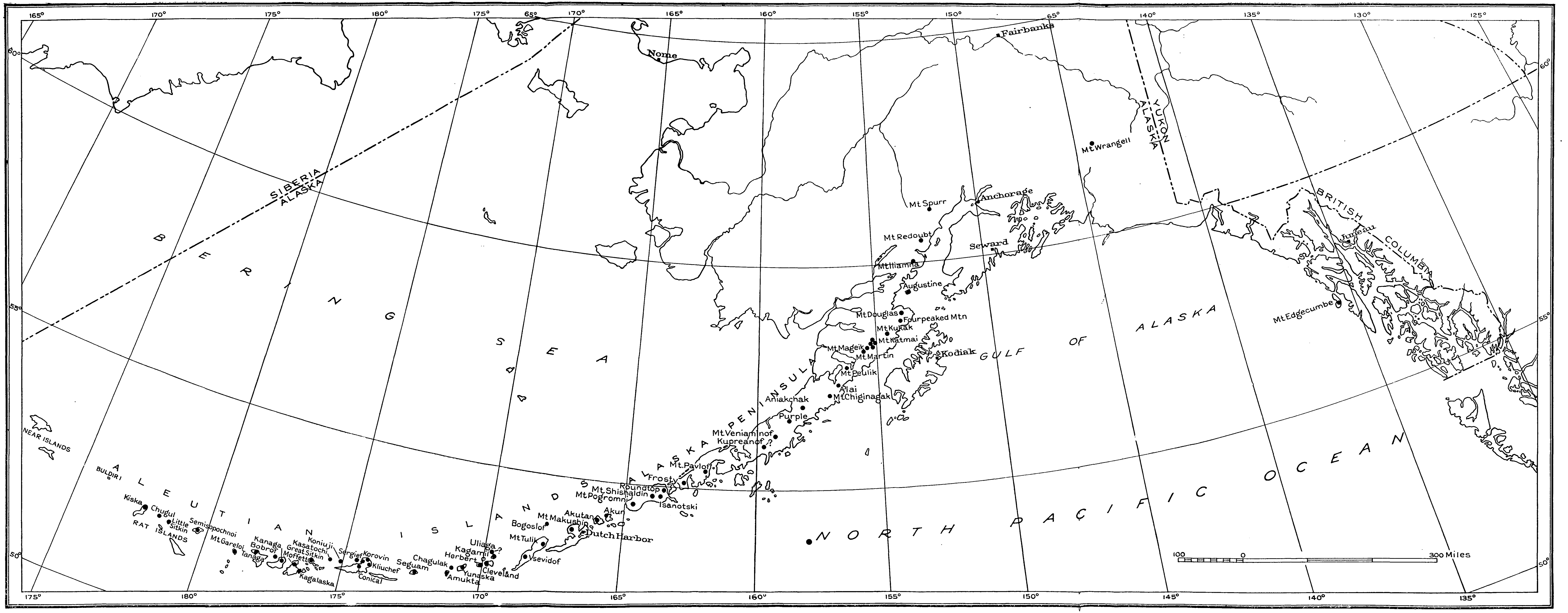
Jurassic volcanic rocks are represented on Gravina and Prince of Wales Islands, near Ketchikan, in the Wrangell district farther north, and in the vicinity of Juneau. The determination of the age of these various units rests on somewhat slender grounds and can by no means be regarded as fixed. In the Ketchikan district these rocks are dominantly coarse andesitic breccias, which grade successively upward into fine-grained tuffs and then into slate and limestone. At the localities on Prince of Wales Island a number of lava flows also make up part of the sequence, and their composition ranges from andesite to basalt. In the Wrangell district the supposed Jurassic volcanic rocks are schistose melaphyre breccia, with intercalated tuffs and flows, which are associated with slate and graywacke. In the Juneau area two distinct volcanic units, which Martin tentatively considered of Jurassic age, have been distinguished. These in ascending order are the Thane volcanic group and the Douglas Island volcanic group. The Thane group consists at its base of tuff and slate, overlain by limestone, which in turn is succeeded by melaphyre tuff. The total thickness of this group is estimated to be about 5,000 feet. These rocks are immediately underlain by members of the Gastineau volcanic group, which are considered by Martin to be Upper Triassic. Overlying the Thane group is the Treadwell slate, which immediately underlies the Douglas Island volcanic group. This volcanic group consists of an enormous assemblage of melaphyre flows, tuff, and agglomerate having an estimated thick-



A. ELLIPSOIDAL GREENSTONES OF MESOZOIC AGE ON WEST SIDE OF KNIGHT ISLAND IN PRINCE WILLIAM SOUND.

B. MOUNT SHISHALDIN.

Altitude 9,387 feet. One of the inspiring volcanic cones that form part of the great chain of active volcanoes of Tertiary to Recent age that extends through southwestern Alaska and the Aleutian Islands.



MAP SHOWING DISTRIBUTION OF VOLCANOES IN ALASKA.

ness of about 15,000 feet. No conclusive evidence as to its age has yet been found, and the assignment to the Jurassic is necessarily tentative. North of Juneau the so-called †Berners formation includes some interbedded lava flows and tuff that are more or less similar in composition and on the line of strike of the Douglas Island volcanic group. In the sedimentary members of the †Berners formation some fossils have been found that are provisionally assigned to either the Jurassic or the Cretaceous, with the weight of probability favoring the Jurassic. Whatever age is finally decided upon for these sedimentary members would also apply to the igneous members, with which they are intimately associated.

COPPER RIVER REGION

The great thickness of basaltic flows known as the Nikolai greenstone may be in part of Triassic age, though certainly its lower members are Permian. These flows are apparently overlain without recognizable unconformity by limestone of Upper Triassic age. There would, therefore, be no direct counter evidence against assuming that these lavas accounted for the entire interval between the known Permian and Upper Triassic sedimentary formations, if it were not for the fact that nowhere else in Alaska has a lower Triassic formation been recognized. It therefore seems extremely unlikely that these lavas were poured out continuously throughout this interval. In the absence of definite evidence that the greenstones are in part of Triassic age, they have been regarded for the purposes of this report as Permian.

Certain volcanic rocks lying east of Skolai Pass near the terminus of Russell Glacier have not been fully differentiated from nearby members of the Carboniferous system, and there is still considerable doubt as to their correct age assignment. Martin, however, states that the weight of evidence now available favors the assignment of the lava and pyroclastic beds to the Triassic. Evidently he was influenced in reaching this conclusion by the general agreement of the geologists most familiar with these rocks in correlating them with the Nikolai greenstone. This argument, however, fails in view of the preponderance of evidence that the Nikolai greenstone, in part at least, is Permian.

The only places in the Copper River Valley where volcanic rocks of Jurassic age are known to occur are near Taral and at the mouth of the Chitina River. At the Taral locality, associated with a massive conglomerate, are tuff beds that contain a typical Tuxedni fauna, of Middle Jurassic age. At the mouth of the Chitina River comparable tuffaceous slate beds also contain typical Middle Jurassic marine forms. No complete section of these beds has been found, but the incomplete section studied was several hundred feet thick.

COOK INLET-SUSITNA REGION

At numerous places in the Cook Inlet-Susitna region volcanic rocks, mainly of assumed Triassic age, have been recognized. The age of most of these rocks has not been well established, and many of their relations are analogous to those of the Nikolai greenstone, which have already been discussed, though the evidence is by no means so definite as for the Nikolai greenstone. The most northern of these localities are at the head of the Susitna River and between that stream and the Gulkana River. There the rocks are basaltic lava flows and tuffs associated with some shaly beds. The composition of the rocks is dominantly diabasic, and many of the separate flows show numerous amygdules. Some andesitic flows also occur in the sequence. The total thickness of these volcanic rocks and the sediments associated with them is about 3,500 feet. Moffit regarded these rocks as probably late Carboniferous or early or Middle Triassic, a determination that seems to be the only one that can be reached from the information now available.

In the Ohio Creek Valley of the Chulitna River Basin, Capps found abundant tuff beds in the lower part of the Triassic sequence. These are succeeded by various distinctly sedimentary beds, including conglomerate and limestone, and still higher in the section there is a considerable thickness of lava flows, some of which show amygdaloidal cavities. The tuffaceous rocks can be traced northeastward into the valley of the West Fork of the Chulitna, but the lava member has practically disappeared.

In the Matanuska Valley and in adjacent parts of the Talkeetna Mountains andesitic greenstones and other rocks, both igneous and sedimentary, have a wide distribution. The great bulk of the greenstones are said to show clearly that they are the products of explosive volcanic action, but intercalated with these volcanic breccias, agglomerates, and tuffs are distinct sheets of amygdaloids, porphyries, and flow breccias. At least 1,000 feet of these lavas and associated rocks have been observed. The members have been subjected to some deformation and faulting. Fossils have been collected from some of the tuff beds and have been identified as belonging to the lower part of a Middle Jurassic fauna. In the area east of Chickaloon Creek and in the nearby Nelchina area beds of tuff from 1 to 4 feet thick are interbedded with sandstones, shales, and other nonvolcanic rocks. These tuffs are said to have a very different appearance from those mentioned above, as their color is much darker and they consist almost entirely of fragments of glassy striated feldspar, hornblende, and quartz. Sheets of lava are also reported in the area, and the rocks of which they are composed appear much fresher than the lavas in the Middle Jurassic unit. The stratigraphic evidence shows that these younger lavas and tuffs unconformably overlie the Middle Jurassic rocks. For this and other reasons these younger volcanic rocks have generally been correlated with the Upper Jurassic series, but Martin has suggested that some of the tuff beds may be Lower Cretaceous. Evidence is not yet available from which to decide between these alternative assignments.

In the Anchorage district greenstone volcanic tuff occupies an extensive area in the mountains from the Knik River to Turnagain Arm and extending south into the Hope district. Capps also reported some rhyolite tuff and small amounts of lava flows associated with these more basic phases. The tuff is usually greenish, owing to the large amount of chloritic alteration products it contains, and its matrix is usually composed of carbonates and serpentinous materials, though in places it is glassy. This unit is separated from the Cretaceous graywacke-slate assemblage of sedimentary rocks by a marked angular unconformity, so that it is unquestionably younger, but how much younger is indeterminate. Parks, because of the dissimilarity of the volcanic rocks to the known Eocene rocks in the neighborhood, tentatively assigned them to the uppermost part of the Upper Cretaceous, an assignment that is entirely in accord with all the facts now known but is not necessarily final.

Near the base of the Mesozoic sequence on Kenai Peninsula are ellipsoidal greenstones of diabasic composition. These rocks are widely exposed along the shores of Kachemak Bay, in the extreme southern part of Cook Inlet. Dominantly they consist of scoriaceous and ellipsoidal lava interbedded with a small amount of tuff. These volcanic rocks rest on slates and graywackes of supposed Paleozoic age. Although their contacts with the underlying rocks do not show whether or not the two are conformable, the less altered appearance of the volcanic members indicates that they are much younger and probably unconformable. The volcanic rocks are overlain by Triassic chert without apparent stratigraphic break. It is therefore generally assumed that the volcanic rocks are Triassic, though it is by no means certain that the lower members may not be Carboniferous. Indeed, the general position of the volcanic rocks is such as to strongly suggest correlation with the Nikolai greenstone of the Copper River region, whose age has already been discussed.

Near the top of the Triassic section exposed in the Seldovia area of Kenai Peninsula is a series of limestone and tuff beds. The volcanic portion of this section includes tuff, tuffaceous conglomerate, and breccia. No reliable measurements of the volcanic member of this unit have been made, but probably it is at least several hundred feet thick. The relations of this assemblage with the overlying rocks are indeterminate, but the fossils collected from the included limestone beds form the basis for correlation of them and the associated volcanic rocks with the Upper Triassic series.

The oldest Jurassic volcanic rocks that have been recognized on Kenai Peninsula are a series of tuff and volcanic agglomerates, which are interbedded with marine sedimentary beds. This assemblage crops out along the shore of the peninsula between Seldovia Bay and Point Bede. The distribution of the volcanic beds with those of distinct marine origin is such as to indicate that both were laid down under marine waters. No accurate measurement of the thickness of these beds has been made, but it seems safe to estimate that 2,000 to 3,000 feet of rocks are included in the section. Fossils that have been collected in considerable numbers from the tuff members of the sequence place those beds in the Lower Jurassic series, though the evidence is not definite enough to determine their exact position in the series.

On the west coast of Cook Inlet volcanic rocks of Mesozoic age have been recognized at many places from the Yentna district, on the north, to the Kamishak district, on the south. It has not been practicable to represent the distribution of these volcanic rocks on the accompanying geologic map (pl. 1) by the appropriate distinctive igneous symbol, because they are so intimately associated with sedimentary members that the two types have been treated as a unit in the field investigations. Both the volcanic rocks and the sedimentary members are therefore included in the single pattern for undifferentiated Mesozoic rocks in that part of the area which extends from the Skwentna River on the north to Lake Iliamna on the southwest. These rocks doubtless do not constitute a single unit but were formed at different times during the Mesozoic era. Thus, in the vicinity of Lakes Iliamna and Clark there are certain greenstones that are now assigned to the Upper Triassic. On the whole, however, the observations have not been complete enough to allow close determination of the age of the component members, and the entire assemblage, though believed to be dominantly Jurassic, has not been more closely assigned than to the Mesozoic era. As a whole, this unit consists of volcanic material that includes tuff, breccia, and lava flows. In general these rocks range in composition from andesite to basalt, but some more acidic phases, such as rhyolite, have been recognized. Many of the lava flows are finely banded and show well-marked flow structure. Apparently none of these members are greatly deformed, and the dips are relatively low. Some faults have been noted, but the amount of displacement has not been determined. These volcanic rocks, where seen by Spurr in the eastern foothills of the Alaska Range, were named the Skwentna "series" and assigned to the Jurassic system. Later and more extensive studies have shown that the Skwentna group includes other members and may have a longer time range. To sum up the present consensus of opinion regarding these rocks, it may be said that the positive evidence from the region is that these volcanic rocks are younger, though not much younger, than the Upper Triassic and are distinctly older than certain of the known Upper Cretaceous beds.

OTHER AREAS

Undoubtedly some of the great assemblage of Mesozoic volcanic rocks in the Cook Inlet region extend farther south into southwestern Alaska, but so far they have not been definitely recognized. At a few points, such as near Cold Bay and on Kodiak Island, the recognized Mesozoic sedimentary sequence appears to rest on greenstone volcanic rocks, whose relations and age are not known with precision but which may be of Mesozoic age. Such a correlation has been suggested by Martin, who bases it on their supposed equivalence with the greenstones in the Copper River region—an analogy that is of somewhat doubtful value. The general absence of Mesozoic volcanic rocks in surface exposures in southwestern Alaska may be due to the waning of volcanic activity in that region during Mesozoic time, or, more probably, to the burial of such rocks under deposits of the later-formed material which makes up so conspicuous a part of the geologic sections exposed there.

Much of the highland that lies between Norton Bay and Eschscholtz Bay, near the eastern limit of Seward Peninsula, consists of andesitic volcanic rocks. In general these are dark gray or greenish and on exposed surfaces have a peculiar spotted appearance due to the alteration of the feldspar crystals that make up a large part of the rock. Both hornblende and pyroxene varieties occur. In addition to these flow rocks there are some breccias of the same chemical composition. Little definite information as to the age of these effusive igneous rocks is available. They clearly overlie the members of the metamorphic assemblages on the peninsula and are practically unsheared, though they have been broadly deformed, like all the nearby rocks up to and including the Cretaceous. The eroded fragments of these volcanic rocks are recognized as pebbles in the Ungalik conglomerate, of Cretaceous age. From the foregoing facts it seems hardly justifiable to attempt to date these volcanic rocks closer than by assigning them to the Mesozoic era, and even that assignment must be regarded as distinctly tentative, for the late Paleozoic history of this part of the peninsula is practically unknown.

In extreme northern Alaska and forming practically the uppermost member of what is now recognized as the top of the section of Upper Cretaceous rocks are several beds of bentonite interstratified with shale and sandstone. Microscopic examination of this material revealed the fact that it represents rather clean falls of volcanic ash, which has been little reworked by subsequent agencies. Apparently the original volcanic rock from which the ash was derived was a latite or sodic andesite. Beds of this material were recognized in the valleys of the Kigalik, Utukok, and Avalik Rivers.

In the Prince William Sound area there is a complex assemblage of rocks consisting in part of greenstone. This assemblage from time to time has received different designations and correlations. Some members form parts of the Orca group, and others have received only more general lithologic designations. In general the greenstones range from fine-textured ellipsoidal flows to more massive diabase. Both types include amygdaloidal varieties. In the finer-grained rocks the groundmass is mainly glass, in which porphyritic crystals of labradorite feldspar are common. Subsequent to their formation these rocks have suffered considerable alteration whereby sericitic and chloritic material has been developed. No definite information is available as to the precise age of these volcanic rocks, and such general facts as are available lead only to a broad identification of the rocks as probably Mesozoic. Fortunately, at certain places within the Prince William Sound area, notably near Ellamar, Latouche, and Knight Island (pl. 15, *A*), the greenstones have been mapped separately from the other rocks with which they are associated, so that for those areas the distinction can be shown on the accompanying map (pl. 1). In other parts of this same area, however, the field data are not adequate to permit their separation, and while there may be some volcanic rocks in these areas they have not been differentiated from the more abundant sedimentary rocks, and both have been included, without distinction, as undifferentiated Mesozoic rocks. Possibly the volcanic rocks that are reported to occur in the Controller Bay region, especially on Wingham Island and in the Yakutat group in the vicinity of Yakutat Bay, may be the eastward extension of certain of the volcanic rocks in the Prince William Sound area. Much more field evidence will have to be collected before this suggestion can be regarded as more than an interesting speculation.

TERTIARY TO RECENT VOLCANIC ROCKS

Compared with the approximate cessation of volcanic phenomena in the later part of the Mesozoic era, the Cenozoic era presents a striking contrast. Not only have scores of Alaska volcanoes been active during historic time, but they and their predecessors, from Tertiary time on, have taken a large part in molding the present appearance of extensive tracts of the Territory. In fact, the continuity of volcanic activity in several of the areas has made it necessary, in the absence of a sharp line of demarkation between the two, to describe the Tertiary to Recent volcanic rocks as more or less of a unit. Although many of the Tertiary centers of volcanism have continued active down to the present day, there are some areas in which that action has ceased and presumably other areas in which volcanism was initiated later than the Tertiary.

As the distribution of volcanoes is of considerable general interest it seems desirable, before describing the various Tertiary-Recent volcanic deposits in the individual Alaska regions and districts, to indicate those places where volcanoes are now active or where cones built up by their action are so well preserved that they are now conspicuous features of the landscape and probably were active within the last few hundred years. The distribution of these volcanoes is shown graphically on plate 16. In this illustration it has been necessary to generalize the information from various sources, and this has resulted in some inconsistencies. The most significant of these has come about through showing only one volcano in a group, though subsidiary cones of prominence may be well known. For instance, in the Katmai area only a few of the numerous vents have been indicated; in the Pavlof area only one volcano has been indicated, though the so-called Pavlof Sister is perhaps almost equally entitled to recognition. Others such as Mounts Drum and Sanford, in the Copper River region, although unquestionably of volcanic origin, appear to be so dissected that it is doubtful whether they have been active within the indefinite period that may be considered as only "the last few hundred years." Other small craters, such as some in the St. Michael area, near the mouth of the Yukon, or the reported crater in the White River district, near the international boundary, are so little known that it is uncertain as to how lately they have been in eruption, and they would further be disqualified because they are not conspicuous features in the landscape. Sixty named peaks are included in the volcanoes shown on plate 16, and they extend in a great arc from Mount Edgecumbe, on Kruzof Island near Sitka, in southeastern Alaska, through Mount Wrangell, in the Copper River region, and the whole Alaska Peninsula and the Aleutian Islands, to Kiska, near longitude 177° E. This arc subtends an air-line distance of nearly 2,000 miles, measured between the end points, or is nearly 2,500 miles long if measured in 100-mile steps along the curving course passing through the main peaks.

Scenically these volcanoes are among the most inspiring of the many natural attractions of Alaska (pl. 15, *B*). Unfortunately, most of them are situated in regions of sparse population, little visited by outsiders, and therefore their grandeur is seldom seen by those who would appreciate it most. Although none of the volcanoes of southwestern Alaska or the Aleutian Islands reach so great heights as some of the well-known volcanoes in other parts of the world, such as Popocatepetl (17,816 feet), in Mexico, Mauna Kea (13,825 feet), in Hawaii, and Fujiyama (12,232 feet), in Japan, in the perfection of symmetrical outline and the whiteness of their snow-clad upper slopes many of these Alaska volcanoes that stand 8,000 to 11,000 feet above the sea rival or excel in beauty many of the almost venerated volcanoes of better-known lands. Recognition of the value to the public of preserving for its use some of these volcanic areas for all time has led the Government to set aside as a national monument the Katmai volcanic area. This was an especially happy selection, because, in spite of the present general inaccessibility of the area, the events following the great outburst of that volcano in June 1912 have been observed and recorded by scientists and others, not only immediately after the eruption but at frequent intervals during the succeeding years. Many articles by Griggs [20] and others give entertaining and instructive information about the Katmai eruption and the steps Nature has taken to remodel the country after that event.

SOUTHEASTERN ALASKA

The oldest of the recognized Tertiary volcanic rocks of southeastern Alaska are certain rhyolitic and andesitic flows and tuffs that crop out on Gravina, Zarembo, Kupreanof, and Kuiu Islands. They seem to grade upward into conglomerates and nonvolcanic rocks. At most places these beds rest unconformably on rocks that are much older. The age of the volcanic rocks has not been definitely determined at most exposures, but there seems to be no question that they are Tertiary and probably were formed toward the middle of Eocene time. The total thickness of this igneous assemblage, together with the associated sedimentary rocks, is in the neighborhood of 1,500 feet. Still higher in the stratigraphic column in southeastern Alaska are basaltic and andesitic lava flows associated with small amounts of sedimentary rocks. These rocks are especially well exposed in the southwestern part of Admiralty Island and on Kupreanof and Kuiu Islands, paralleling Keku Strait, and scattered small patches occur at intervals as far south as the Ketchikan district. According to Buddington, these lavas and pyroclastic rocks have a thickness of about 2,500 feet. The greater part of them appear to be the result of fissure eruptions by which the lava filled existing valleys and even submerged the tops of some of the hills. They probably were formed during Eocene time.

On Suemez Island, off the west coast of Prince of Wales Island, is a rather extensive area of rhyolite, obsidian flows, andesite, and basalt that, because of its isolated position, cannot be correlated closely with the other Tertiary volcanic rocks. Buddington called attention to the apparent similarity of these rocks to those of the Admiralty-Kupreanof-Kuiu area, just described, but in spite of that comparison he was inclined to correlate the volcanics of Suemez Island with

[20] Griggs, R. F., The Valley of Ten Thousand Smokes, 340 pp., Washington, Nat. Geog. Soc., 1922.

those of Graham Island, in British Columbia, which have been assigned to the early or middle Pliocene. No other rocks representative of the Pliocene series have been recognized in southeastern Alaska.

Volcanic rocks of Quaternary age have been recognized as occurring in small tracts at many places along the mainland, on Revillagigedo Island in the Ketchikan district, and as an extensive area forming most of the southern half of Kruzof Island, near Sitka. So recent are some of the deposits in the Ketchikan district that Wright[80] in describing an occurrence on the Unuk River states: "The ashes from these eruptions can still be seen as black patches on the mountain peaks 8 to 10 miles distant." Other occurrences in the Ketchikan district are along Behm Canal, near Smeaton and Rudyard Bays, at the "Punchbowl", and at New Eddystone Rock. The composition of practically all of the lava at these places is basaltic, but at Winstanley Island the rock is much lighter colored and is more correctly described as an augite andesite.

The Quaternary volcanic rocks of Kruzof Island all bear a close areal relation to Mount Edgecumbe. This volcano, reported on somewhat doubtful evidence to have last been in eruption in 1796, is composed mainly of basic andesites or basalts, which display great diversity in their color, texture, and crystallinity. According to Knopf, much of the mass of Mount Edgecumbe is postglacial, though doubtless some of the volcanic rocks more remote from that center may be considerably older.

COPPER RIVER REGION

In the central part of the Copper River region the Wrangell Mountains form a majestic cluster of volcanoes consisting of at least four major centers of eruption—namely, Mounts Wrangell (14,000 feet) (pl. 17, *B*), Drum (12,000 feet), Sanford (16,210 feet), and Blackburn (16,140 feet). Of these only the first-named has been seen actively "smoking." To judge from the amount of dissection these various cones have undergone, the oldest is Drum, with Blackburn, Sanford, and Wrangell successively younger. This, however, is not an entirely reliable criterion, as proximity to master streams may have been a controlling factor. Apparently volcanism in this region did not begin until some time after an early Tertiary plain of erosion had been formed, uplifted, and somewhat dissected. Evidently this must have been somewhat along in the Tertiary, possibly not earlier than late Eocene. Since that time there has been almost unceasing volcanic activity in different parts of the area, during which the present huge agglomeration of flows, breccias, and tuffs has accumulated. Most of these rocks are porphyries of medium coarseness and light- or dark-gray color. In composition the usual type is a hypersthene or hornblende andesite, but more basic or more acidic phases range from basalt to dacite. The color of these rocks also shows a considerable variation from the type, as brick-red, pink, lavender, brown, and greenish tones are by no means rare. The eastern limit of the lavas in the Copper River region that may be correlated with the Wrangell lava is in the mountains adjacent to Skolai Pass, where they cap many of the highland areas and unconformably overlie Paleozoic and younger sedimentary rocks. That the lavas in this area are correlative with the older members of this volcanic series seems clearly indicated by the extensive dissection they have undergone, whereby the deep valleys of Skolai Creek and the Nizina River and Nizina Glacier have been deeply trenched through them. None of these Tertiary-Recent lavas show evidence of marked deformation after they were poured out. It is true that in general they display low dips that radiate from the volcanic centers. These dips in part are believed to mark the original slope on which the tuffs were laid down or on which the lavas flowed. Probably there has been some broad doming of the region through widespread warping and elevation, but this type of movement has by no means been large. The thickness of the lava series differs considerably in different places, and no measurements are available that disclose the total thickness of these beds in the heart of the range. Partial sections have shown more than 4,000 feet of these volcanic rocks near Regal Glacier, in the Nizina Valley.

COOK INLET-SUSITNA REGION

Overlying the sedimentary coal-bearing and associated rocks in the Matanuska area and extending both eastward into the Nelchina area and northward into the Talkeetna Mountains is a series of nearly horizontal basaltic flows which with their intercalated tuffs and breccias attain a thickness of at least 1,000 feet. They have been deeply dissected by the streams, so that they now occur mainly as cappings of the highlands. These lavas apparently were poured out on a surface of gentle relief that had beveled across the older sedimentary rocks. Uplift subsequent to their extrusion brought the lavas into their present elevated position. The igneous rocks display a wide variation in physical character and chemical composition. Highly glassy types, amygdaloids, porphyries, and fine-grained facies have abundant representatives. They are usually more acidic than normal basalt, and few of them contain notable quantities of olivine. Probably the most satisfactory descriptive name for rocks of this sort is andesitic basalt.

In the Nelchina area similar volcanic rocks were recognized by Chapin, but there they seemed rather more acidic than in the Matanuska area. The oldest flow in the Nelchina area appears to have the com-

[80] Wright, F. E., The Unuk River mining region of British Columbia: Canada Geol. Survey Summary Rept. for 1905, pp. 50–51, 1906.

position of dacite. Higher in the series are rhyolites and rhyolite tuffs of light color and with pronounced flow bands. Amygdaloidal andesite forms the surface rock throughout a considerable area on the divide between the Jack River and Tsusena Creek. On the whole there can be little doubt that this volcanic series is of Tertiary age. There is, however, ground to doubt whether there may not be some members that have not been separately mapped that are somewhat older. The main doubt arises with regard to the dacite, which is recognized as the oldest member in the Nelchina area, because it is reported that this rock is intruded by large bodies of granite and has experienced metamorphism which has not affected the other lavas.

In the Broad Pass area, especially in the vicinity of Seattle Creek and less notably on Brushkana and Soule Creeks, there are considerable masses of acidic effusive rocks, mainly of rhyolitic, trachytic, and andesitic composition. Little is known regarding their relations with other rocks, but they appear to have been poured out subsequent to the cooling and consolidation of the Tertiary granite that occurs in the same general region. In general composition these lavas resemble certain of the later lavas in the Nelchina district, and little doubt is felt that further studies will strengthen the basis for the correlation of the two. For the present all that can be said is that they were probably poured out fairly late in the Tertiary—probably in the late Eocene or the Miocene.

Near the mouth of Revine Creek a flow of andesite was found interbedded with members of the Cantwell formation. This lava had abundant vesicles, most of which are partly or completely filled with dark-green serpentine. As this flow is clearly interbedded with sediments of the Cantwell formation, which is now regarded as of Upper Cretaceous age, it follows that the lava also must be referred to that series, though formerly it was considered to be Eocene.

In the western part of the Cook Inlet region and extending into adjacent parts of the Tonzona district of the Kuskokwim region and the Telaquana, Clark, and Iliamna districts of southwestern Alaska are numerous volcanic rocks of Tertiary to Recent age. Mount Spurr is the northernmost member of the definitely recognized chain of volcanoes that stretches southwestward through the Alaska Peninsula and Aleutian Islands. This mountain consists of a great outer crater, now breached by the valleys of several glaciers that flow radially outward. Within this old crater is a new volcanic cone, and from vents near its top steam still issues. An additional small subsidiary vent has been developed on the southern rim of the old outer crater. The rocks of Mount Spurr include breccia, tuff, and lava flows, which have the general composition of basalt. The relation of these volcanic rocks to the nearby coal-bearing Eocene beds is such as to demonstrate that volcanic activity at this place began at least as long ago as the Eocene and has continued with more or less alternation with quiescent periods down to the present time. A similar history seems to be indicated for the other conspicuous volcanoes of this region—namely, Mounts Redoubt, Iliamna, and St. Augustine—all of which are known to have been active within historic time and to have been the sites of volcanic activity for a long time before that.

SOUTHWESTERN ALASKA

Southwestward from the Mount Spurr group, at the extreme northeastern limits of southwestern Alaska, the signs of Tertiary to Recent volcanism become increasingly evident until, south of Chignik, they include practically all the features of the bedrock. The lofty modern volcanoes that overshadow all the other topographic features are dominant in almost every landscape in this region. A partial record of the reported activity of many of these volcanoes up to about 1890 was compiled by Becker.[31] This record, however, is necessarily far from complete, because so many of the volcanoes are in areas almost devoid of population, and even those that are seen by passing vessels or by local residents have not been scrutinized and the observations noted in such fashion that the record is available to others. Unfortunately, interesting as these volcanoes are, it is not feasible to do much more than mention them here, because each has its individual aspects that would well merit a series of volumes to set forth even the fragmentary data that are available and shelves of books if adequate research were done on the multiplicity of problems that they evoke. Their general features, however, may be summarized by saying that the volcanic activity in the region as a whole seems to have begun somewhat after the beginning of the Tertiary and to have persisted intermittently to the present time. The composition of the lavas has in the main been fairly comparable with that of normal andesites, but more basic phases analogous to basalt and more acidic phases approaching rhyolite are by no means unknown. Practically every kind of volcanic activity, from stupendous explosion to quiet welling forth of lava, is represented in different areas and even in many individual volcanoes. Attempts have been made to develop commercially the enormous deposits of sulphur that have been formed by the condensation of the volcanic gases that emanated from some of the volcanoes, but the cost of getting the sulphur to market has been so high that it has not yet proved feasible to utilize this source in competition with those in more accessible regions.

In addition to these piled-up accumulations of lava and volcanic rocks, there are areas, especially in the

[31] Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on general geology: U. S. Geol. Survey 18th Ann. Rept., pt. 3, pp. 14–17, 1898.

vicinity of Lake Iliamna and the country to the south of it, where extrusive flows of lava have mantled the lowland country as great sheets, without any apparent recognizably close connection with known volcanic vents. Some of the flows have a gentle dip, as if tilted, but this attitude may represent the original inclination of the beds as they were poured out over the country. Although usually spoken of as basalts, these rocks should more precisely be described as augite andesites. In the Lake Iliamna area Martin did not find any acidic volcanic rock of Tertiary age. North and west of that area, however, Smith and Capps found some rhyolites and concluded from the field evidence that, although in general the basaltic rocks are somewhat younger than the acidic lavas, there are places where they occur both above and below the basalts. Some sedimentary and tuff beds are associated with the flows. In the vicinity of Lake Iliamna fossils were obtained from beds of that kind near the base of the volcanic section, but they indicate little more than that they belong to a Tertiary flora. Martin, however, on the basis of the general relations of these rocks and their similarity to the Tertiary lavas in the Matanuska region, expressed the belief that both were probably of late Tertiary age.

KUSKOKWIM REGION

Certain of the Tertiary volcanic rocks of the eastern flanks of the Alaska Range that have already been described in the sections on the Cook Inlet-Susitna and southwestern Alaska regions undoubtedly extend over into neighboring parts of the Kuskokwim region, though they have not been specifically identified there. In fact, so much of the Kuskokwim region is still unexplored that any statement as to the geologic features of many areas in it would be extremely unsafe. It is likely, however, that, although as yet undifferentiated from other rocks, representatives of the Tertiary to Recent volcanic rocks may be present at a number of places in the region. The only district in which these late volcanic rocks have been definitely identified is in the vicinity of Goodnews Bay, in the extreme southwestern part of the Kuskokwim region. Here basaltic rocks are widely distributed throughout the valley of the Goodnews River. These include tuffs, thin-sheeted ellipsoidal flows, and thicker, more massive flows. In places they are interlaminated with distinct sedimentary beds of sandstone and argillite. The best exposures of these rocks are said to be near the beach between Beluka Peak and the Tunulik River. The part of the section in which the lavas predominate has an estimated thickness of about 2,400 feet. No definite evidence as to the age of these rocks was obtained, but from their close similarity to the volcanic rocks in the Yukon Valley near Russian Mission it seems that correlation of the two is warranted. On that assumption a Tertiary age for these lavas in the Kuskokwim region has been adopted. Apparently none of the Quaternary lavas are recognized in the Goodnews Bay district, though they have been found both to the north, in the Yukon region, and in the vicinity of Togiak and Bristol Bays, to the southeast.

YUKON REGION

Lavas and associated volcanic rocks of Tertiary to Recent age are most extensively exposed in the western part of the Yukon River Valley, but smaller areas in which these rocks crop out are found in almost every district of that vast region. To describe each of the occurrences, even casually, would require more space than can well be given to the subject here and would, in the main, lead to undesirable repetition. It has therefore seemed desirable to pick out for description only four principal types that present rather distinctive features and let them serve as illustrations of the general subject. The four examples selected are the Tertiary volcanic rocks of the area between the Yukon and Tanana Rivers, the Cosna-Innoko area, the lavas near St. Michael, and the volcanic ash of the eastern part of the Yukon Basin including the area adjacent to the international boundary and the White River. The deposits belonging to the last-named type are not indicated on the geologic map (pl. 1) for reasons that are explained in detail farther on.

In the Yukon-Tanana region Mertie distinguishes two rather distinct volcanic units that are Tertiary or younger. The older of these is found mainly in the southeastern part of that region, especially between the Tanana River and the head of Dennison Fork, though smaller areas have also been recognized near the head of the Charley River and in the vicinity of Manila Creek. These rocks consist mainly of rhyolite, dacite, and andesite, but basalts are practically absent. The rhyolite rocks, which are by far the most abundant, are light-colored and commonly porphyritic, with phenocrysts of quartz and feldspar. The general mass of both the porphyritic and nonporphyritic varieties is fairly fine grained, though the principal dark-colored minerals can usually be identified by visual inspection. The areal distribution of these rocks indicates that they were apparently erupted from fissures, or from several centers, rather than from a single volcanic vent. Little evidence is available as to the age of these rocks except that apparently they are post-Mesozoic and yet not far up in the Tertiary section. It has been suggested that possibly these acidic volcanic rocks are the surface equivalents of the deep-seated Tertiary intrusives of granitic composition. Mertie, however, who is most conversant with the field and laboratory evidence bearing on this question, states that petrographic differences between these lavas and the intrusives are such that the lavas must represent a distinct epoch of volcanism, which he regards as probably earlier than the time of intrusion of the mid-Tertiary granitic rocks. The later

Tertiary or Quaternary consolidated volcanic rocks of this area are best exposed in the vicinity of the Ladue River and extend eastward into Yukon Territory, but smaller areas have been recognized elsewhere, as at Fourth of July Hill, in the Fairbanks district. In addition, there are ash deposits in this area. (See pp. 84–85.) In the Ladue River locality Mertie recognized a small volcanic cone with a well-developed crater which is so little dissected that it must be of fairly recent origin. In general these later volcanic rocks have somewhat the same composition as the older ones just described, in that they are rhyolites and dacites, but they differ in that basalt is common in the younger group and practically absent from the older group. Some of the more basic members have inclusions of ultrabasic composition. From analogy with similar rocks in Yukon Territory it seems likely that all of this younger group is post-Miocene, and the freshness of the volcanic cone suggests that some of them are of Recent age.

Rocks that are regarded as in general comparable to the older of these Tertiary lavas have been reported to occur at several localities in the Koyukuk Valley, from a point near the junction of that stream with the Yukon to the western part of the valley of the Kanuti River, a tributary from the east that enters the Koyukuk near the Arctic Circle. These volcanic rocks are also exposed in the lowland between the Koyukuk and Chandalar Valleys and form considerable areas of bedrock along the West Fork and near the junction of the Chandalar and its East Fork. At the pass between the western tributaries of the Koyukuk and the headwaters of the Selawik River are lavas that are correlated with these Tertiary volcanic rocks.

In the Cosna-Innoko area there are several patches of volcanic rocks, the largest of which extends, with little interruption, from the headwaters of the Chitanana River southwestward at least as far as the headwaters of the Sethkokna River. Other small areas along this general trend occur at intervals through the valleys of the Nowitna and Sulatna Rivers nearly to Mount Hurst. The members of the series in the northern part of this area are predominantly rhyolitic and andesitic porphyries, with flows and tuffs. A single basaltic flow was identified. The age of these rocks has not been determined closely, and it is possible that part of them may have been poured out late in the Mesozoic era, but it seems more probable that they are Tertiary and were erupted at a rather early stage of that system. Farther to the southwest the petrographic character of the related volcanic rocks has been examined in somewhat more detail, and the rocks identified as pyroxene andesites and basalts, many of which show pronounced vesicular cavities and amygdaloidal structure. Evidence as to the age of these flows is fairly conclusive, because they unconformably overlie Upper Cretaceous and Eocene sedimentary conglomerates, none of which contain pebbles of the lavas. It seems evident, therefore, that these volcanic rocks cannot be older than the basal Eocene conglomerates and are therefore either late Eocene or younger. The thickness of the lava probably differed greatly in different places, depending on the configuration of the surface on which they were poured out. Measurements indicating a thickness of at least 500 feet are by no means uncommon, so that it is likely that in places the lavas are very much thicker.

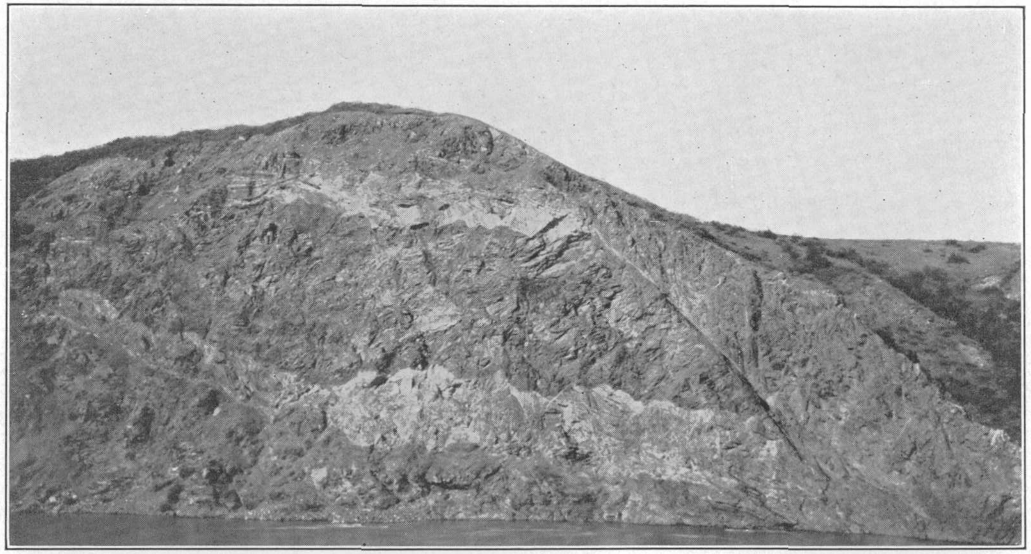
In the western part of the Yukon Valley, at intervals from Kaltag to the mouth of the river, and along the coast to and beyond St. Michael, Tertiary volcanic rocks form numerous exposures. Unquestionably eruption took place at a number of different times and at different centers, and the resulting volcanic rocks show considerable variation in their relations and chemical composition. Information is not yet at hand to permit outlining the areas occupied by these rocks or the interrelations between the rocks in different parts of the area. From the rather meager data now available it appears that the older of these lavas were somewhat more acidic than the later ones, so that while the older lavas were dominantly andesites, the later ones were more typically basalts. It also seems to be indicated that the lavas near the coast, especially in the vicinity of St. Michael, were on the whole much younger than those that crop out along the Yukon. Spurr,[32] in describing the area adjacent to St. Michael, wrote as follows:

> The whole of St. Michael and neighboring islands and of the adjoining mainland appears to be purely volcanic. * * * Where washed clean by the water it [the lava] is wrinkled or ropy, showing it to be the true upper surface of a lava flow. * * * Above this lava comes a bed of water-laid material, chiefly extremely scoriaceous lava, nearly pumice. * * * Volcanic bombs are common. * * * At different points on the island [St. Michael] are four or five eminences, which are only a few hundred feet above the general level. * * * The most conspicuous one is a sharp cone. * * * Another eminence in the interior of the island is shown. * * * Both these eminences and two others which were visited are long-extinct volcanoes. On the top of each is a circular basin surrounded by a steep rock wall. * * * The crater basin is best shown on top of St. Michael Mountain.

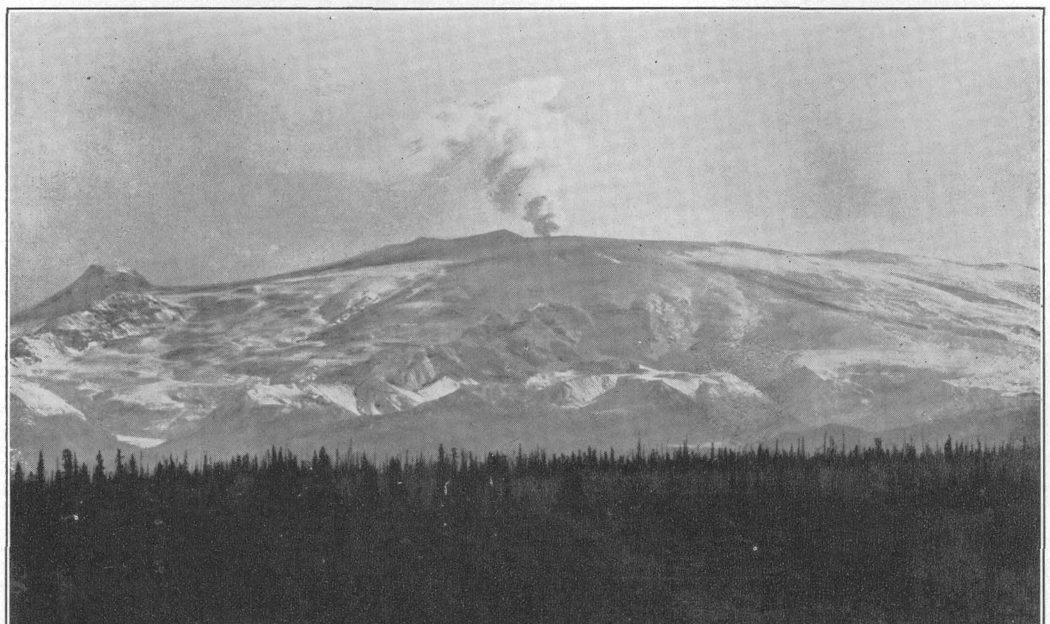
Although Spurr states that the evidence shows that the lava streams cooled beneath the surface of the sea and that he believed it probable that the volcanoes were submarine, such an interpretation does not appear compatible with the well-preserved form of the volcanic cones and their craters. The composition of the lavas near St. Michael, as well as of similar lavas at nearby places, is that of olivine basalt. Such a rock consists mainly of plagioclase, augite, and olivine.

Almost all travelers in the headward portion of the Yukon in Canada and as far down that stream as

[32] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey 18th Ann. Rept., pt. 3, pp. 246–248, 1898.

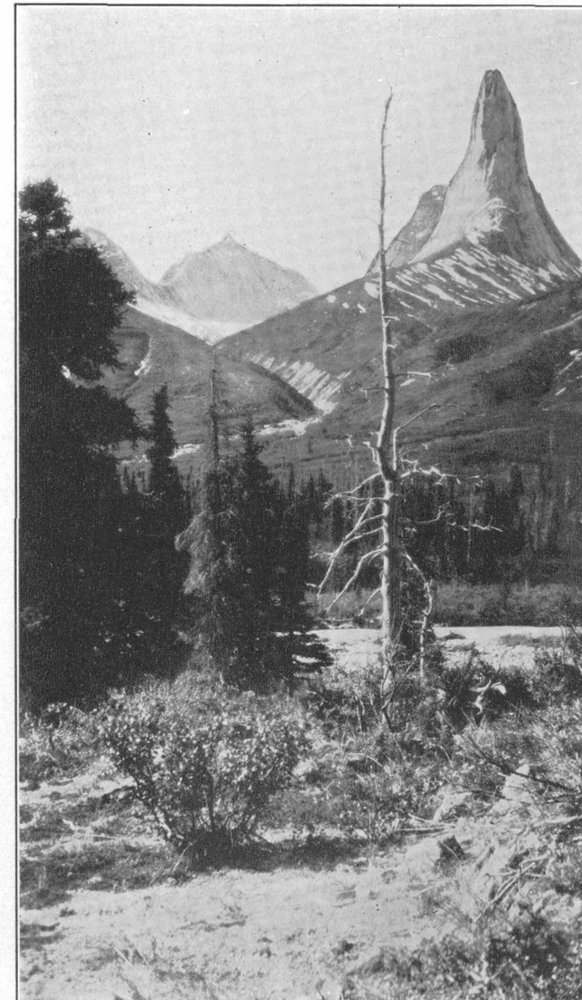


A. BASIC INTRUSIVE DIKES AND SILLS OF MESOZOIC AGE, INJECTED INTO CARBONIFEROUS ROCKS IN THE VICINITY OF NOATAK CANYON.



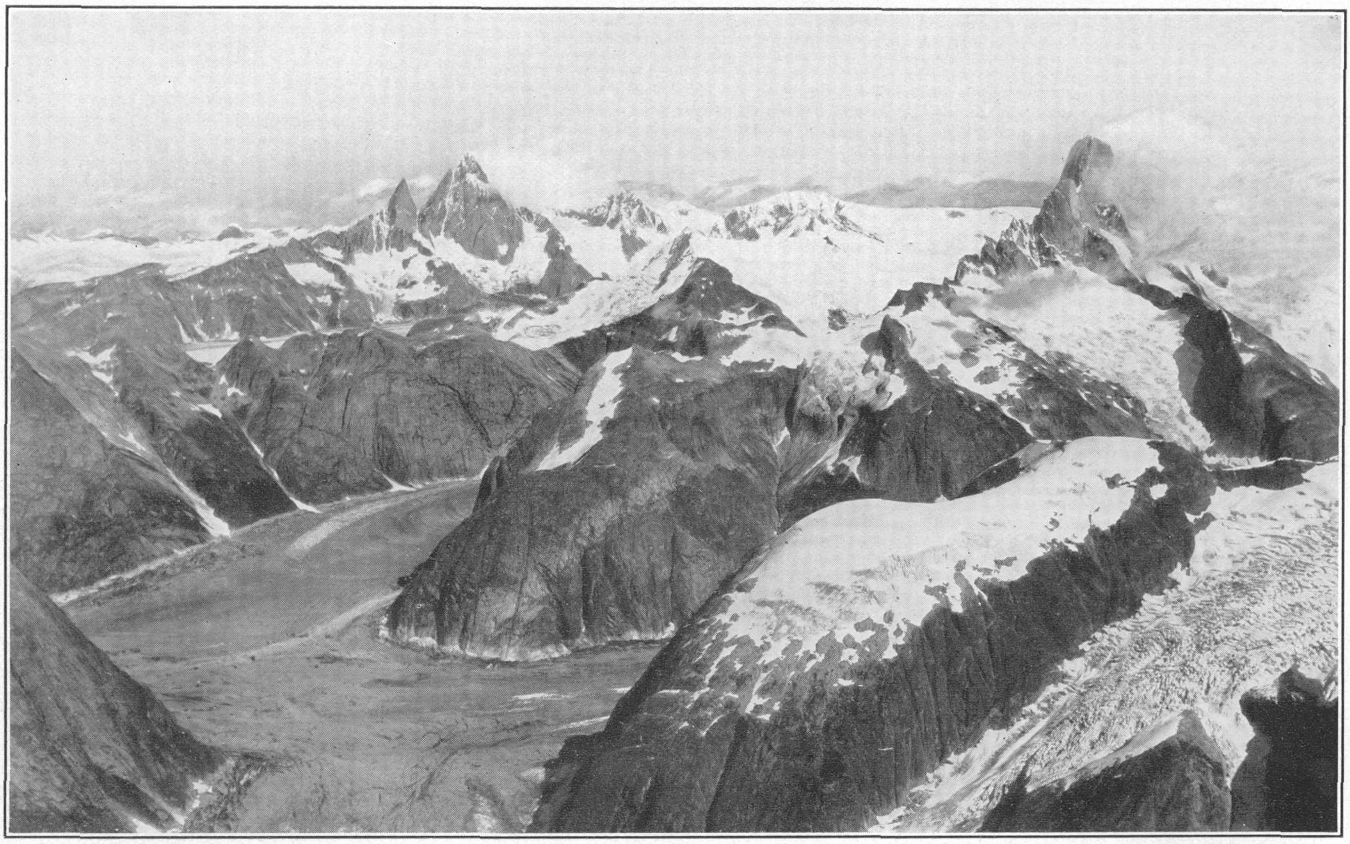
B. MOUNT WRANGELL, IN THE CENTRAL COPPER RIVER REGION.

Altitude 14,000 feet. A center of volcanic activity from Tertiary to recent times.



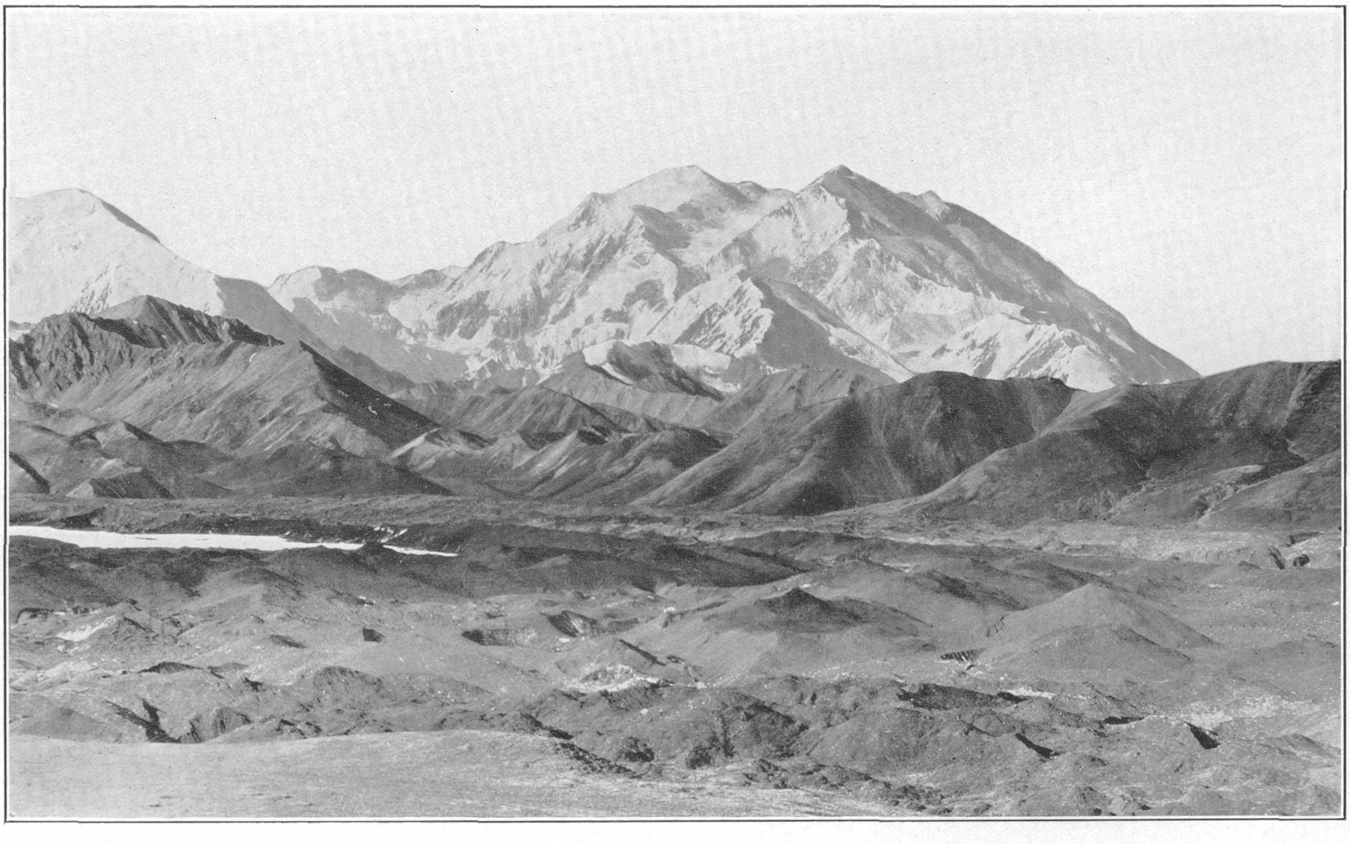
C. A LOFTY SPIRE OF GRANITE IN THE SOUTHERN ALASKA RANGE NEAR MERRILL PASS.

The mass towers as a great tusk with sheer walls nearly 2,500 feet high.



A. THE DEVIL'S THUMB (9,077 FEET), MOUNT BURKETT (9,600 FEET), AND OTHER SERRATE PEAKS THAT MARK THE INTERNATIONAL BOUNDARY IN SOUTHEASTERN ALASKA.

These peaks are composed of the granodiorite of the great Coast Range batholith.



B. MOUNT McKINLEY, THE LOFTIEST MOUNTAIN ON THE NORTH AMERICAN CONTINENT.

Altitude 20,300 feet. Much of the bulk of the mountain is made up of undifferentiated Paleozoic sediments intruded by granitic rocks of late Mesozoic or early Tertiary age.

Woodchopper in Alaska have noticed a peculiar white layer a short distance below the grass roots. This material is volcanic ash that seems to have been blown out by explosive volcanic action from a site near the northern slopes of Mount Natazhat. This occurrence has been described latest by Capps,[33] from whose report the facts given below have been taken. Apparently the tract covered by perceptible amounts of this ash has an area of about 140,000 square miles. Within that tract the thickness of the deposit ranges from a fraction of an inch near Eagle and at Lake Bennett to 200 feet or more in the Kletsan Creek Valley, north of the White River. No flows of lava appear to have accompanied the ash ejection. The ash has the composition of andesite but is extremely pumiceous, so that it is a frothy glass, light enough to float in water. An ingenious method of estimating approximately the date of this explosion was devised by Capps, using the count of the annual rings of trees and other criteria, which led him to announce that it took place some 1,400 years ago. If further check on this estimate establishes its correctness, this layer of ash will serve as a valuable datum plane from which to make many significant comparisons.

SEWARD PENINSULA

Throughout Seward Peninsula are many small areas in which Tertiary to Recent volcanic rocks have been reported, and in the vicinity of Imuruk Lake, in the north-central part of the peninsula, an area of considerably more than 1,000 square miles is covered by these rocks. So recent are some of these lavas that the ropy surface of the original flow is still preserved, and in places they have flowed out over gravel of late Tertiary or Pleistocene age. Typically these volcanic flows are composed of dark-gray or nearly black lavas, usually very scoriaceous or spongy in appearance, having the mineral and chemical composition of basalt. Undoubtedly not all these basaltic lavas were poured out contemporaneously, for in other places the lavas cap hills below which the present streams have carved their valleys. In those places the lavas are old, though from such evidence as is available they are not so old that they antedate the Tertiary. Furthermore, some of the gravel deposits over which the younger lavas flowed contain pebbles derived from earlier lavas. These flows must have had very significant effects on the drainage lines of the region by filling up some of the stream channels and causing the streams to take up new courses elsewhere. As many of the old stream courses elsewhere were the sites of placer concentration, the determination of the location of those that have been thus buried under the lava might have considerable economic value and well repay a search to discover them. No definite evidence has been found as to the source from which the lavas were extruded. Possibly they may have welled up through fissures which became obliterated by the eruptions. Moffit suggests that the lavas in the Noxapaga and Kuzitrin Valleys may have come from a source southwest of Lake Imuruk, as is indicated by the direction of movement shown by the flow lines in the lava itself. Obviously other centers must have given rise to the patches of lava found in other parts of the peninsula, as, for instance, north of Teller, in the western part, or in the valley of the Mukluktulik River, in the southwestern part.

Not only are these Tertiary to Recent lavas widely distributed throughout Seward Peninsula proper, but they are found in adjacent parts of nearby regions. Thus, to the south of Seward Peninsula these lavas are present at intervals all the way to the area near St. Michael, notably in the southern part of the Koyuk Valley and in the lowlands to the east, in the Reindeer Hills and Island Point west of Shaktolik, on Besboro Island in Norton Sound west of Iguik Creek, and near Unalakleet. In the area north of Seward Peninsula similar lavas have been reported as cropping out at several points in the northern part of the Buckland River Valley, and probably if the area were more thoroughly explored these lavas would be found in parts of the lowlands of the Selawik Valley.

BERING SEA REGION

Tertiary to Recent volcanic rocks have been found on practically all the islands of the Bering Sea region south of the Diomede Islands, including St. Lawrence, Hall, St. Matthew, the Pribilofs, Nunivak, and Nelson Islands, and have been described by Hall[34] and Dawson,[35] from whose notes the following statements have been taken. In the Pribilof group, on the island of St. Paul, the bedrock is dominantly formed of volcanic material. Apparently the oldest member of the sequence is a massive flow of lava that has the composition of olivine basalt. Later much more scoriaceous or pumiceous flows with tuff were poured out. The recency of these eruptions is shown by the fact that a dozen or more cones or vents that have remarkably symmetrical outlines and well-preserved craters have been found on the island. One of the most striking of these craters stands at an elevation of about 600 feet and seems to have been the principal focus from which some of the flows emanated. Some of the craters now hold small lakes on their floors. St. George Island shows features practically identical with those on St. Paul, but the cones are not as numerous. A vent near

[33] Capps, S. R., An ancient volcanic eruption in the upper Yukon Basin: U. S. Geol. Survey Prof. Paper 95–D, pp. 59–64, 1915.

[34] Hall, J. S., Geology of the Pribilof Islands: Geol. Soc. America Bull., vol. 3, pp. 496–500, 1892.

[35] Dawson, G. M., Geologic notes on some of the coasts and islands of Bering Sea and vicinity: Geol. Soc. America Bull., vol. 5, pp. 117–146, 1894.

the center of the island, at an elevation of about 900 feet, seems to have been the source of many of the flows. Although the evidence is by no means complete, the general consensus of opinion places the age of these volcanic rocks as post-Pliocene.

In the group of islands lying some 250 miles north of the Pribilof group and including St. Matthew, Hall, and Pinnacle Islands, no distinct craters have been recognized, nor any of the very recent basalts. However, these islands are composed almost exclusively of volcanic rocks that seem to be somewhat older and more decomposed than those of the Pribilof group. The series consists of lava flows and tuff beds, which have in general a southward dip on St. Matthew Island and a northward dip on Hall Island. The lavas are in general somewhat more acidic than the rocks on the Pribilof Islands and have a composition that places them in the group of andesites. Many of these rocks are porphyritic and have a purplish or gray color. According to Dawson, at least part of the sequence was formed under water. Pinnacle Rock, which was at one time regarded as a volcanic chimney, seems more likely to be the remnant of an eroded sequence of flat-lying volcanic rocks. The rocks of these islands are now regarded as not older than Tertiary.

St. Lawrence Island, which lies some 150 miles southwest of Nome, is apparently composed of a variety of different rocks whose distribution has not yet been determined. Among them, however, and apparently forming a considerable part of the bedrock of the island, are numerous volcanic rocks which are said to be much more scoriaceous and agglomeratic than the flows noted in the more southern groups of islands. According to Dawson no cones or craters occur on the island, though earlier reports [36] had indicated that such features had been recognized, and a photograph of the country near Cape Kialegak that accompanies a report by Collins [37] shows a peak whose form is highly suggestive of a volcanic cone. Collier [38] suggested that apparently none of the volcanic rocks on St. Lawrence Island were older than Pleistocene.

On Nunivak Island and in the western part of Nelson Island volcanic rocks that seem indistinguishable from the basaltic rocks already noted at points along the lower Yukon, at St. Michael, and in Seward Peninsula, form much of the bedrock. Like the volcanic rocks at those places, they are regarded as Tertiary to Recent, and some of them are so recent that they still preserve many surface features formed as they flowed out over the country.

[36] Miner, J., Report on the cruise of the *Corwin*, pp. 137–140, 1881.

[37] Collins, H. B., Jr., Prehistoric Eskimo culture on St. Lawrence Island: Geog. Rev., vol. 22, p. 111, 1932.

[38] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougarok, Port Clarence, and Goodhope precincts: U. S. Geol. Survey Bull. 328, p. 103, 1908.

INTRUSIVE ROCKS

Noteworthy because of the insight they furnish of past geologic events and processes, the intrusive igneous rocks also merit special consideration because many of them are conspicuous producers of some of the grandest of the Territory's majestic scenery, and some of them have a close relationship to the mineralization that has supported the industry which, in about half a century, has furnished minerals to the value of more than $700,000,000. Unfortunately, in spite of their importance, the time is not yet ripe for adequately describing and classifying these various intrusive rocks, either as to their age, chemical composition, or relationships. In the following pages and on the accompanying map (pl. 1), therefore, the writer has been forced to combine as one mapping unit all the known intrusive rocks, regardless of the facts that some of them are pre-Paleozoic and others of various intermediate ages up to and including the Tertiary, and that in composition they range from the most basic to the most acidic.

As is apparent from the map, there is hardly an area 50 miles in radius, except in northern Alaska, in which no intrusive rocks are indicated. Had the scale of the map been larger, or had exploration been more complete, the number of areas of intrusive rocks would have been increased many fold, because obviously on this map only the larger areas could be shown, and the outlines of even those areas have necessarily been much conventionalized.

Two general papers that may be of especial service to one wishing a somewhat more detailed statement of some of the intrusive activity that has taken place in parts of Alaska have recently been prepared by Mertie.[39] These papers, together with the still more detailed reports on specific areas, contain a wealth of material that must not be overlooked if the history of these stupendous events is to be fully understood.

SOUTHEASTERN ALASKA

In southeastern Alaska the invasion of the great Coast Range batholith and associated intrusions in middle and later Mesozoic time so overshadowed all earlier intrusive action in that region that in the absence of detailed studies it has been practically necessary to pass over all the intrusions that may have occurred in preceding geologic periods and start with those of late Mesozoic age. Such a course necessarily leads to the suppression of many of the incidents in the geologic history of the region, for it is known that not only were there many periods of igneous activity whereby the volcanic rocks already described were brought to the surface but there were probably also

[39] Mertie, J. B., Jr., Pre-Cambrian and Paleozoic vulcanism of interior Alaska: Am. Geophys. Union Trans. 16th Ann. Meeting, pt. 1, pp. 292–302, 1935; Mountain building in Alaska: Am. Jour. Sci., 5th ser., vol. 20, pp. 101–124, 1930.

some intrusions of the deep-seated batholithic type which properly should be discussed in this section of the report. Evidence of such deep-seated intrusions in the Paleozoic or earlier era is referred to on page 16, where, in describing certain of the Silurian beds, mention was made of the fact that some of the pebbles and cobbles in conglomerates of that system are composed of coarse granitic rocks. Obviously the granitic intrusives from which these pebbles were derived must have been intruded before that time, their covering rocks eroded away, and the granite thus exposed broken down and transported by streams or other agencies and laid down in the marine waters of the Silurian period—a series of events that necessarily took a long time for its accomplishment.

The most comprehensive and intensive studies of the intrusive igneous rocks of southeastern Alaska have been set forth in a report by Buddington,[40] and it is from that report that the following statements, covering only the most general facts, have been taken. In the main the dominant feature of southeastern Alaska is the great composite batholith and its numerous satellitic intrusions (pls. 18, *A*, 13, *A*, and 13, *B*). The main mass, which is usually referred to as the Coast Range batholith, has a length of more than 1,100 miles, from the northern part of the State of Washington northwestward to a point in Yukon Territory in latitude 62° N., near the international boundary, and a width in places of more than 100 miles. Less than a third of this mass lies within the limits of southeastern Alaska. The intrusive rocks here grouped together are predominantly of siliceous, subalkalic composition, but locally many variants are found ranging down to those of ultrabasic composition. The ultrabasic rocks comprise olivine-rich rocks (diorites, wehrlites, and saxonites) pyroxenites (hypersthenites or bronzitites, diallagites, and augitites), and hornblendites. The core of the Coast Range batholith appears to consist predominantly of rocks close to granodiorite in composition, and those on the western flanks, in Alaska, may be classed as quartz diorites. True granites are found, but so far as now known they form only a relatively small proportion of the intrusive rocks. Some variation in composition of the batholith has been noticed, both along and across its major dimensions, but the variation across it seems to be far more pronounced than that parallel to its length.

Buddington considers that the Coast Range batholith and related intrusives fall into six more or less well defined parallel belts, each of which has certain features in common among its component parts and differs from the other belts. These belts he describes under the following headings, beginning at the extreme northeast: Border zone east of the Coast Range batholith, Coast Range batholith, Wrangell-Revillagigedo belt, Prince of Wales-Chichagof belt, Kuiu-Hecate belt, and Dall-Baranof belt. In the main batholith the rocks are prevailingly gneissoid near the margins, but in the central part of the batholith only an indistinct gneissoid structure is apparent. Evidently the main batholith has been subjected to considerable stresses subsequent to its complete solidification.

The source of the material, the method of its injection, and the various processes that accompanied and followed the placement and consolidation of that vast amount of molten rock are still matters of conjecture. Inasmuch as the intrusives seem to be somewhat similar in composition and character and to have been intruded more or less contemporaneously, they are commonly believed to have been derived from a common magma and to have acquired such local variations as they now exhibit through the complicated interaction of obscure geologic processes, chief among which is the so-called magmatic differentiation. Such an interpretation at best leaves many things unexplained, or glossed over, by the use of terms that imply processes but little understood, so that much more detailed work must be done before any of the major problems connected with this stupendous injection of molten rocks can be regarded as even tentatively solved. In the absence of such work, attempts to solve other problems based on those matters become even more futile and subject to error. For instance, if all the intrusives were not essentially contemporaneous, the generalization given above fails, and conjectures as to the general age of the rocks by application of that criterion become even less reliable.

That a long time must have been involved in the intrusion and consolidation of these great batholiths seems obvious, so that exact contemporaneity would be incredible. Therefore there can be considerable justifiable difference of opinion as to whether all the intrusions were "essentially" contemporaneous, or whether some were sufficiently distinct to be regarded as separate intrusions. Certain evidence is cited by Buddington that shows that in places in southeastern Alaska one intrusive cuts and brecciates another, thus indicating some difference in age. He concludes that so far as southeastern Alaska is concerned there is no evidence to disprove the assumption that all these Mesozoic intrusive rocks may be of Lower Cretaceous age, though from facts observed in adjacent areas it seems most likely that they may be in part of Jurassic age and in part Cretaceous. The assignment of at least part of this intrusive episode to the Jurassic period seems to fit in best with certain observations made in the Cook Inlet-Susitna region and southwestern Alaska. The whole problem, however, requires much more intensive study before a definite conclusion can be reached, so

[40] Buddington, A. F., and Chapin, Theodore, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800, pp. 173–253 1929.

that it must suffice here to assign the main mass of intrusives in southeastern Alaska to the later part of the Mesozoic era.

A few small masses of intrusive rocks of Tertiary age have been recognized in southeastern Alaska. One area of this sort passes through Eva Island, the peninsula on Kupreanof Island between Hamilton Bay and Keku Strait, Pup Island, Point Camden, and the head of Threemile Arm, Kuiu Island. The rock in the vicinity of Point Camden is unique in that analcite forms in places as much as 10 percent of the gabbro. The rocks in this belt are basic, having the composition of diabase or gabbro. At the north end of Keku Strait an intrusive was found which has the composition of dacite porphyry. At the north end of Zarembo Island a mass of granite porphyry appears to be so closely associated with Tertiary volcanic rocks that it is believed to be of Tertiary age also. It consists of feldspar phenocrysts in a groundmass consisting of a micrographic intergrowth of quartz and feldspar and has small lenses filled with kaolin and chlorite.

YUKON REGION

In the Yukon region there are many areas in which intrusive rocks have been recognized, and the larger ones are shown on the accompanying map (pl. 1). These intrusives are especially numerous and extensive in the eastern part of the region between the Yukon and Tanana Rivers, but sporadic masses occur in the Alaska Range, which forms the southern boundary of the region, and on the southern flanks of the Brooks Range, which limits the region on the north, and smaller masses extend southwestward from the Chandalar district to and beyond the Iditarod district.

In the area between the Yukon and Tanana Rivers the character, distribution, and age of the various intrusive rocks have been determined with greater exactness than almost anywhere else in the Territory. For this reason, although representatives of some of the intrusives recognized there doubtless occur in other parts of the Yukon region, the description of the intrusives in that area may serve especially well as an indication of the general types that may occur at other places in the region.

Evidence of five principal epochs of intrusive activity has been recognized in the area lying between the Yukon and Tanana Rivers. Two of these epochs are regarded as pre-Paleozoic, and one each in the Paleozoic, Mesozoic, and Cenozoic eras. The oldest of these igneous rocks consist of an assemblage of basic rocks including amphibolites, hornblendes, and chlorite schists, in the main of intrusive origin but possibly including some extrusive rocks as well. Younger than these basic rocks is the Pelly gneiss, which consists principally of rocks of granitic composition but includes more basic phases, such as monzonite, diorite, and even gabbro. All these rocks are intensely metamorphosed, so that their original features are almost entirely obliterated by secondary characteristics that have been imposed on them. These two pre-Paleozoic units have not been separately mapped but are included on plate 1 within the areas occupied by the pre-Paleozoic rocks. The principal Paleozoic intrusives are a series of ultrabasic and basic igneous rocks that have been considerably altered into serpentinous and chloritic material. The next younger recognized period of profound intrusive activity came in the middle part of the Mesozoic era. During that episode granite, quartz diorite, and, very rarely, some quartz monzonite were injected as enormous batholiths. The latest great intrusions took place in Tertiary time, and the rocks are characterized by general monzonitic composition, though granites and other differentiates, either more acidic or more basic, are common. The Paleozoic, Mesozoic, and Tertiary intrusive rocks are indicated by appropriate symbols but are not differentiated from each other on plate 1.

The oldest of the pre-Paleozoic intrusive rocks in the Yukon-Tanana area are now so highly metamorphosed that little can be determined as to their original characters, and few specific statements can be made as to their distribution, geologic relations, or age. Much additional and more intensive field investigation will be required before their history can be sketched even in general terms.

The Pelly gneiss presents several different lithologic phases and in its structure ranges from rather massive to extremely contorted schistose rocks. It is especially well developed in the extreme eastern part of the Yukon-Tanana area and extends for a considerable distance into Canada—in fact, it is from the Canadian area that it derives its name. An extremely common type of the gneiss is characterized by abundant augen, usually of feldspar, which range from several inches in diameter to microscopic dimensions. From the field evidence there can be little question as to the correctness of the assignment of the Pelly gneiss to the pre-Cambrian. It is, however, still a matter of considerable doubt as to just when, during that long period, its intrusion took place. Obviously, it must be younger than the rocks it intrudes, but until the stratigraphic succession is more adequately worked out this does not lead far in placing a close time limit on its age. However, it is believed that, on the whole, the intrusion occurred late rather than early in pre-Paleozoic time.

The Paleozoic intrusives are especially well-exposed in two principal areas, one beginning at the Tanana River near the mouths of the Chena and Salcha Rivers and extending west-northwestward to the head of the Salcha River, and the other lying east of the batholith in the valley of the Charley River at the head of the Seventymile River and continuing southeastward to and beyond the international boundary. Small bodies of similar rocks have been recognized near Livengood and in the valley of Troublesome Creek. In general these rocks have an ultrabasic or basic composition and are partly or completely altered into serpentine and chloritic products. They are now so much altered that their original features cannot be determined with certainty, though apparently most of them are of intrusive origin. Near Livengood, however, some black glassy rocks that are considered members of this group suggest by their relations and appearances that they may be lava flows. A significant feature of some of the basic intrusives is that near Livengood they contain chromite and other chrome- and nickel-bearing minerals. A small nugget of platinum was found in the course of placer mining in one of the creeks draining southwestward from this area. These facts suggest the possibility that commercial deposits of chrome, nickel, or platinum may occur in the vicinity of these ultrabasic rocks. It has not yet been possible to determine closely the age of these rocks, but from the best available information it seems that, for the present, the best surmise that can be made is that they are probably not older than Devonian nor younger than Mississippian.

Presumably the Mesozoic intrusive rocks have the most extensive distribution of all the intrusive rocks in the Yukon-Tanana area and, from many points of view, are the most important. The largest surface exposure is in an irregular-shaped area in the basin of the Charley River that is about 80 miles long and some 50 miles wide in its widest part. Another large area embraces a tract of more than 1,000 square miles south of the Charley River area. More than 80 other bodies of these rocks have been recognized within the limits of the Yukon-Tanana area, though rather definitely restricted to the eastern part of the area—say from the vicinity of Fairbanks to the international boundary. As noted above, the common types of these intrusives are granites and quartz diorites, most of which are coarse-grained granular rocks composed dominantly of quartz, potash and soda-lime feldspars in varying proportions, biotite, and hornblende, with several accessory minerals. There are, however, many variants, toward both the more acidic and the more basic ends of the sequence. In fact, the type of exceedingly acidic intrusive which is practically devoid of all dark-colored minerals derives its name "alaskite" from specimens of rock comparable with some of those occurring in this region. A basic phase equivalent to gabbro was identified as occurring in Ketchumstuk Mountain and in bluffs of the Tanana River below the Tok River. Because of the absence of suitable horizons of reference from which to determine the age of these various intrusives, little more can be said than that they are post-Paleozoic and pre-Tertiary. The fact, however, that elsewhere in Alaska a great period of intrusion is known to have occurred in Jurassic time strongly suggests a correlation of these rocks in the Yukon-Tanana area with that event. Such an interpretation does not run counter to any of the known facts and seems to fit in well with the general geologic record. For instance, no Jurassic rocks of marine origin have been recognized anywhere in the great inland province north of the Alaska Range. Such a condition may well be interpreted as due to extensive uplift of the country at that time, whereby the sea was driven beyond the limits of the area. The cause of that uplift can only be conjectured, but the deep-seated intrusion of great masses of igneous rocks might well have accomplished or caused these profound orogenic movements. Such speculations necessarily have no firm basis of facts on which to rest, and it has therefore seemed entirely unwarranted at this time to go further than to regard these intrusives as of Mesozoic age, with the probability that they may have been formed in Jurassic or early Cretaceous time.

The latest of the five groups of intrusives mentioned is composed dominantly of monzonites and related granular rocks. As a whole the surface exposures of these rocks are somewhat smaller than those of any of the other groups. Their smaller extent is probably to be explained as due to the fact that less of their original cover has been stripped from them, so that only their upper parts are exposed. Most of these latest intrusives occur in the region west of Fairbanks, especially in the Hot Springs and Rampart districts. Among the areas of these rocks may be mentioned those northwest of Hot Springs, in the Tolovana Basin east of Idaho Creek, on Roughtop Mountain at the head of Boulder Creek, and on Elephant, Wolverine, and Sawtooth Mountains in the Rampart district. These rocks are usually light to dark gray and in the larger masses have medium to coarse grain. In most specimens the rock is composed principally of feldspar, pyroxene, and biotite, with subordinate amounts of accessory minerals, such as apatite, magnetite or ilmenite, and zircon. Some of these later intrusives carry a little cinnabar, a mineral that apparently has never been found in the Mesozoic intrusives of Alaska. The fact that some gold mineralization seems to have been introduced by these intrusives, though of economic importance, is not a criterion that can be used in distinguishing these younger intrusives from those of Mesozoic age, because gold mineralization accompanied both. Decisive evidence as to the age of the later intrusives is not available from the Yukon-Tanana area itself, but from nearby areas there is ample justification for assigning them to the Tertiary and some basis for believing that they may be as recent as the Miocene.

The other areas in the Yukon region where more specific evidence has been obtained as to the age of the

Tertiary intrusives are in the Ruby, Innoko, and Iditarod districts. Intrusives of similar petrographic character and chemical composition have also been recognized in the Kuskokwim River region, where evidence of their Tertiary age has also been obtained.

In the Alaska Range most of the large instrusive bodies are of granitic composition. This is true of the batholithic masses that form much of the northern flanks of Mount McKinley and its adjacent highlands, including Mount Foraker (pl. 18, *B*). Doubtless part of the cause of the loftiness of Mount McKinley, which is the highest peak on the entire North American Continent, lies in the resistance to weathering of the intrusive rocks of which it is in part composed and their effect in indurating the sedimentary rocks through which they were injected. For a long time these granitic intrusives in the Alaska Range were considered to be of Jurassic age. Although it is still possible that some of them may be as old as that, Capps has shown that certain of them definitely cut members of the Cantwell formation, which are considered to be of Upper Cretaceous age. Pogue has also reported somewhat similar conditions in the vicinity of Broad Pass, where the granites are assigned to the Tertiary. In addition to these more acidic granular intrusives, basaltic greenstone, andesite, and other rather basic intrusive rocks cut the Cantwell formation, so that they, too, are regarded as probably Tertiary.

OTHER REGIONS

In the surveyed areas of the Copper River region large batholithic intrusive masses are relatively rare, but in the mountains in the unexplored area south of the Chitina River, and probably connecting with the intrusive rocks shown on plate 1, granitic rocks are believed to form much of the bedrock. It is also possible that rock of this type is fairly extensive in the unexplored portion of the Alaska Range in the northern part of the Copper River Valley. Farther west in the Alaska Range, and in the Talkeetna Mountains and the Alaska Peninsula region as far south as Lake Becharof, granitic rocks are extensively developed and form the most rugged and conspicuous features of the landscape. Owing to their occurrence in the most mountainous parts of those regions they are perhaps less well known than many of the rocks associated with them in the more accessible areas, and, in fact, extensive tracts in which they probably occur have not been surveyed at all. Such a tract is the portion of the range lying between Lake Iliamna and the Chakachatna River (pl. 17, *C*), which is believed to be principally formed of these intrusives. Even in those mountain areas where the bedrock is shown as formed of other kinds of rock, it is probable that many tracts are underlain at no great distance below the surface by these intrusives, so that if erosion had removed more of the original cover the area occupied by intrusives would be enormously increased. Throughout this vast area the prevailing intrusive rocks are hornblende granite, hornblende granite porphyry, biotite granite, sodic granite, granodiorite, quartz diorite, and diorite, all showing more or less porphyritic habit. Small amounts of basic intrusives, such as augitite, pyroxenite, and diabase, are associated with the more acidic phases but are of little areal significance. For many years the only available information indicated that some of the granitic rocks, especially those in the Talkeetna Mountains and at points west of Cook Inlet, were younger than certain Lower Jurassic formations and older than certain Middle Jurassic formations. With further explorations additional evidence as to the age of these intrusives in other areas became available, and it is now the consensus of opinion that many of the granitic rocks in this great petrographic province are as young as Upper Cretaceous. This conclusion, however, in no wise leads to discarding the belief that some older intrusives also occur in the province. As Capps has stated, the somewhat gneissic rocks near Iliamna Bay and the granitic pebbles and boulders in the Chisik conglomerate, the Chinitna shale, and the Tuxedni sandstone, all of Jurassic age, clearly necessitate a source from a body of granite older than those sedimentary rocks. It is therefore unwarranted at this time to place the age of the general major intrusive episode more closely than in the Mesozoic era, but it can be stated that certain of the individual intrusions seem to have taken place at different times in the Jurassic and Cretaceous periods.

Intrusives in the area south of the Alaska Range and Talkeetna Mountains have relatively small areal extent and are commonly of rather basic composition. An especially interesting and rather unusual type of intrusive is the dunite or peridotite that occurs in the mountains east of Seldovia and at Port Chatham. The special point of interest regarding this rock is that it contains considerable chromite and other chrome-bearing minerals. In places these minerals appear to be so abundant and concentrated that the rock may have value as a chrome ore, and some shipments of material of this sort have been made in the past.

In northern Alaska most of the mountain area in which extensive intrusions of granitic and allied rocks are likely to occur have been so inadequately explored that the fact that at present only a few such bodies are known is not regarded as indicative that there are no others. In fact, in spite of the meager information available, the belief that many such bodies occur in the highland areas of the Brooks Range is fairly well justified. At present the only definitely known extensive areas of intrusive granitic rocks in this region are at the international boundary, near the head of the Canning River, in the serrate peaks between the Alatna and Kobuk Rivers, in the area between the

Noatak and Etivluk Rivers, especially in the hills adjacent to the Awuna River, in the mountains south of the junction of the Kugururok and Noatak Rivers, and in the hills near the head of the Kivalina River. The gravel deposits brought down by many of the streams from the mountains between the Noatak and Kobuk Rivers and from some of the tributaries of the Chandalar and Koyukuk Rivers strongly indicate derivation from areas of such intrusive rocks. Definite determination of the age of these intrusive rocks has not yet been made beyond the fact that they are younger than the latest of the recognized Paleozoic rocks and therefore presumably not older than the Mesozoic. The known widespread intrusion of granitic rocks elsewhere in Alaska during the middle and later part of the Mesozoic era gives ground for presuming that some of these intrusives in northern Alaska also were formed in the course of that same general event, though it is by no means unlikely that some of them may have been injected as recently as the Tertiary. In addition to these acidic intrusives, others having the composition of gabbro and norite have been reported, though little detailed information has yet been obtained as to their areal distribution or age. Such basic intrusives were seen in the vicinity of the canyon of the Noatak, where the rocks intrude Mississippian sandstones and shales (pl. 17, *A*).

In Seward Peninsula there are several areas in which siliceous intrusive rocks are common. Among the larger areas of this sort are the Kigluaik, Bendeleben, and Darby Mountains, but sporadic occurrences have been found all the way from the easternmost part of the peninsula, in the hills between the Buckland and Kiwalik Rivers, to the westernmost tip near Cape Prince of Wales, and even to the Diomede Islands, in Bering Strait. Probably not all these intrusives are of the same age, for certain of them are highly gneissic, as if they had been subjected to severe mountain-building movements, whereas others are extremely massive and unsheared. In general the more massive rocks are typical granites composed dominantly of quartz, orthoclase feldspar, and biotite, with plagioclase feldspar as an abundant accessory. In the eastern part of the peninsula the intrusive rocks are usually somewhat more basic and approach diorite in composition. One of the important features, from a commercial standpoint, is that most of the granites in the western part of the peninsula seem to have caused tin mineralization. This is especially the case at Cape, Potato, Brooks, Black, and Ear Mountains. Placers and lodes formed near the flanks of some of these mountains have yielded tin minerals to the value of about $1,500,000, and the undeveloped placers and lodes in their vicinity are likely to become among the most important of the domestic sources of tin.

There is reason to believe that all these acidic intrusives are not contemporaneous, but facts are not yet available to allow separation of those of different ages and assignment to the appropriate geologic period or era. Certain of the strongly gneissic masses may be as old as pre-Paleozoic and comparable with the Pelly gneiss of the Yukon region, although there is no definite evidence on which to base such a suggestion. Others are certainly post-Paleozoic, as for instance the granitic intrusives at Cape Mountain, which cut Carboniferous rocks. So far as known, not any of the granitic rocks of Seward Peninsula are as young as Tertiary, though the absence of well-defined Tertiary beds with which to make the necessary comparisons makes such a statement of doubtful value. To judge from analogy with other parts of Alaska, it seems probable that the bulk of the batholithic intrusions of Seward Peninsula occurred during the Mesozoic era and, if so, probably in its middle or later part.

CORRELATION CHART

In the foregoing pages the descriptions have been so arranged as to give some impression of the geologic happenings throughout the various parts of Alaska at different specified times—for instance, during the Carboniferous or Triassic periods. Obviously it has not been possible to go far in such correlations or to subdivide minutely those long stretches of the geologic past. If the presentation has accomplished its purpose, it will have given some slight sense of the diverse conditions that have prevailed in different parts of the Territory more or less simultaneously, while uniform conditions prevailed in other parts. In other words, in small measure it should have allowed the reconstruction of some of the scenes that would have greeted our eyes at different periods, had we been there and looked around as we now view our existing geography. It also should have given some feeling as to the many changes that have occurred, whereby ocean bottoms have become the sites of present mountains, and former floods of lava have been superseded by stagnant swamps in which coal formed. But the method that was adopted does not bring out this aspect of the subject well, because the accounts of successive events in each of the different areas may be widely separated in the text, and to trace the series of events in southeastern Alaska, for example, would require endless skipping about through the pages to collect all the information about that area and to eliminate material that is not pertinent to that end. For that reason, as well as to summarize in condensed form many of the facts already stated, it has been considered desirable to give here in columnar form in the accompanying table an abbreviated epitome of the principal kinds of deposits formed in the different main regions of Alaska during each of the geologic periods. Each of these columns, thus placed side by side, if read vertically, allows a ready recognition of the sequence of events in a specified region, or, if the chart is read horizontally from one column to another, it gives a comparison of the contemporaneous happenings in the different regions. (See chart, in pocket.)

In using this chart the limitation imposed by lack of definite information, as well as the inflexibility brought about by a system of hard and fast space restrictions, should be constantly kept in mind. Otherwise, the chart will have the appearance of greater exactness than is warranted. Instead, it should be considered rather as a conventionalized diagram in which the best available approximations are somewhat graphically portrayed. The space allotted on the chart to a specific system or series bears no relation to the proportional length of time embraced by that period or epoch to the whole length of time represented by the geologic column. Instead, this space has been allotted solely in a way to meet the need of showing the available record. Thus the space allotted to the recognized members of the pre-Paleozoic section is only a small percentage of the total column, though pre-Paleozoic time may well have been longer than all geologic time since.

The precise position of the descriptive text within the space allotted to the different epochs has been determined mainly through availability of room rather than through an attempt to indicate distinct stratigraphic position. As a matter of fact, for many of the units described the available information has been indicated with perhaps more than justifiable definiteness to place it even in the appropriate epochs, so that to go further would in general introduce an appearance of unwarranted precision. The true stratigraphic sequence within a specified geographic district, however, has been indicated so far as practicable by allotting a separate line or lines to the appropriate descriptive text for each unit and placing that for the youngest unit in that district at the top. Each district noted within a specified epoch, however, is an entirely separate entity, and the true position of its stratigraphic units is not to be inferred from their position on the chart with respect to those in another district, which, for convenience, may have been recorded above or below that district in the space allotted to a specified series or epoch. Within these spaces the districts have been arranged in the main in geographic order, from south to north and from east to west, so that on the whole the descriptions of nearby districts are given in reasonably close proximity.

Although the description of the different series has been placed in the appropriate space, so far as can be done from the information available, some of the units recognized evidently are not yet known with sufficient exactness or include members of more than one series. For such units an attempt has been made to show graphically the possible range in age. This has been done by drawing lines from the appropriate descriptive text of such length that they include the presumed range which the unit embraces. Where these limits are not well determined the lines are broken and question marks inserted to indicate the doubt that exists. Doubtless rigorous application of this method of representing uncertainty as to the precise age limits of some of the units would have required an even greater multiplicity of such lines. However, this would have confused rather than clarified the established facts, and therefore it was decided to depart somewhat from meticulous accuracy for the sake of serving what was considered to be of general significance.

Limitations of space on the chart and its already crowded condition have necessitated omitting specific indications of unconformities or other stratigraphic relations between the various units designated. This information is in part supplied by the preceding descriptive text but is also in part suggested by the chart in places where there are long gaps in which no unit is specifically mentioned in successive series. The converse of this condition does not follow, however, and at several places stratigraphic breaks have been recognized in the section even within a single district and within a single series.

Such other conventions and arrangements as have been adopted for expressing graphically the various relationships are so obvious that they do not need explanation. The fact should be reemphasized, however, that this chart should not be used except in connection with the text, because it is so extremely condensed that many of the qualifying and restrictive statements that safeguarded the generalizations have necessarily had to be dispensed with. In fact, even the text has been so boiled down from the more detailed reports that it presents only a skeleton of the more outstanding generalities, so that, for a full understanding of the known facts, the reader should have recourse to those reports for a really adequate statement.

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