UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Bulletin 933-B

GEOLOGY OF THE NUTZOTIN MOUNTAINS, ALASKA

BY FRED H. MOFFIT

With a section on the

IGNEOUS ROCKS

By RUSSELL G. WAYLAND

GOLD DEPOSITS NEAR NABESNA

BY RUSSELL G. WAYLAND

Mineral resources of Alaska, 1940
Pages 103-199

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1943

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - Price 65 cents

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GEOLOGY OF THE NUTZOTIN MOUNTAINS, ALASKA

By Fred H. Moffit

ABSTRACT

The Nutzotin Mountains constitute the eastern end of the Alaska Range, which extends in a great arc across southern Alaska and either merges with the Coast Range or dies out as an independent range in the vicinity of the international boundary. The part of the Nutzotin Mountains considered in this report lies on the northeast side of the Wrangell Mountains and extends from the Nabesna River southeastward across the Chisana River to Beaver Creek. It is an area of rugged mountains, many peaks being between 6,000 and 7,000 feet in altitude and one, Mount Allen, reaching 9,478 feet. Many of the higher mountains are covered with perpetual snow and so become the gathering ground of the ice that feeds numerous glaciers. The two largest streams of the area are the Nabesna and Chisana Rivers, which originate in huge glaciers on the slopes of the Wrangell Mountains and flow in narrow, canyon-like valleys cut directly through the Nutzotin Mountains, finally uniting to form the Tanana River. Two smaller streams, the Snag River and Beaver Creek, rise within the area, but they are tributary to the White River, which flows into the Yukon.

At present the usual route of transportation into the district is over the highway up the Copper River to Nabesna and then by pack trail to the destination. More recently the airplane has supplanted the older forms of transportation to a considerable extent.

The oldest rocks of the district form a small area of schist and phyllites associated with altered granitic intrusives along the southwest border of the Tanana lowland. The next oldest rocks include basaltic flows, intrusives, and volcanics, which are interbedded or associated with a minor proportion of limestone, shale, and other clastic beds that are in part of Devonian and in part of Permian age. However, the dominant rocks of the district, which form most of the Nutzotin Mountains, are of Mesozoic age and include Upper Triassic limestone, Upper Jurassic, Lower Cretaceous, and Upper Cretaceous shale, arkose, graywacke, conglomerate, limestone, and other clastic deposits. These beds are much folded and faulted but are not schistose. Unconformities or discontinuities probably separate the groups of deposits belonging to each of the different epochs. Moreover, with the possible exception of the Upper Cretaceous sandstone, shale, and conglomerate, the bedded rocks were intruded by dikes, sills, and large irregular bodies of granitic rock, belonging for the most part to the granodiorite family.

Finally, a thick series of basaltic and andesitic lavas and other volcanics rests unconformably on the older rocks in places and completes the stratigraphic section of consolidated deposits. Extrusion of these younger volcanics began in Tertiary time and has continued intermittently to the present. The flows are tilted but are not folded and have been eroded extensively by glacial ice and the processes of normal erosion.

Prospecting for gold and copper began in the district at an early date and led to the discovery of the Chisana gold placers, which have been in continuous production since 1913, and the lode-gold deposit of the Nabesna Mine, at White Mountain, on the Nabesna River, where gold production began in 1931.

INTRODUCTION

LOCATION OF THE AREA

This paper deals primarily with the geology of the part of the Nutzotin Mountains extending southeastward from the Nabesna River to Beaver Creek and the boundary between Alaska and the Yukon

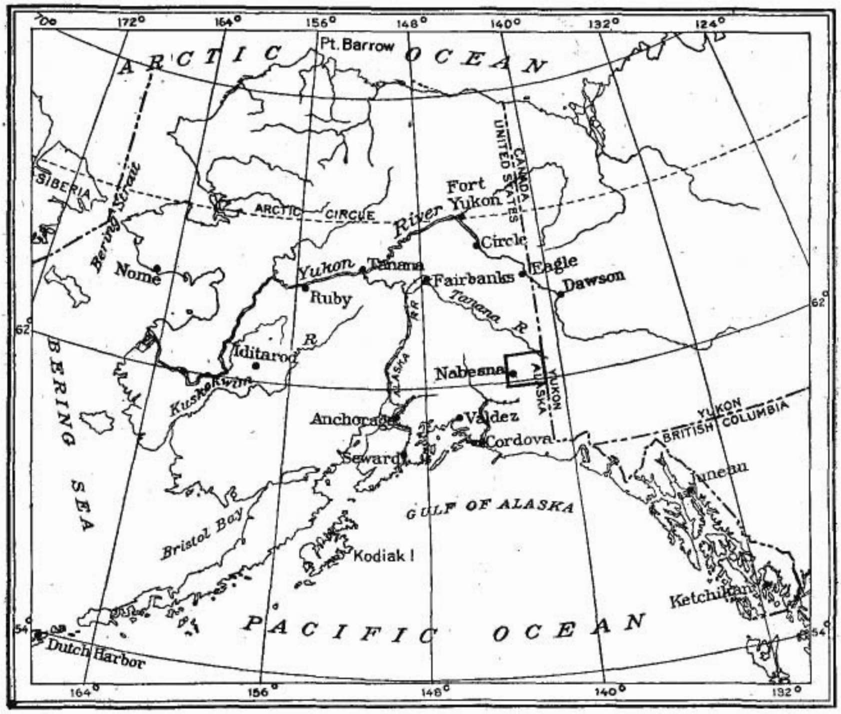

FIGURE 4.—Index map of part of Alaska showing area described in this report.

Territory. In addition, some adjoining country northwest of the Nabesna River is considered in order to make clear the relations of the formations as they occur on the two sides of the river. The area to be described is shown on the index map, figure 4.

This area includes the Nabesna gold mine, on White Mountain, between Jack and Jacksina Creeks, and the Chisana placer-gold district near the head of the Chisana River, both of which have been important producers of gold. It therefore is an area of economic importance, and although the production of gold is now reduced much below that of former years it may long continue to be of importance.

The field work represented on the geologic map (pl. 2) was partly a revision of work previously done by the writer and others and partly an extension of mapping into areas hitherto unmapped, as will appear from the descriptions that are to follow.

PREVIOUS WORK

It will be unnecessary for the purpose of this report to do more than make a brief reference to the geologic investigations in the district south of the Nabesna River previous to 1914, since they were exploratory and are now superseded by later, more comprehensive investigations, which were carried on under more favorable working conditions, particularly under less pressure of time.

In the course of an exploratory trip from Pyramid Harbor to Eagle in 1899, W. J. Peters, topographer, and A. H. Brooks,[1] geologist, followed a route that led them up the White River to its head, across the divide to the Chisana River, thence by way of Cooper Pass to the Nabesna River, down Nabesna River to the pass leading to the Tetling River, and down the Tetling River to the Tanana River. Much of this territory is within the area considered here. Necessarily the observation of geologic features that could be made during such a rapid exploratory trip was restricted.

Three years later, in 1902, D. C. Witherspoon, topographer, and F. C. Schrader, geologist, made a topographic and geologic reconnaissance survey of the northern part of the Nutzotin Mountains from Mentasta Pass to the Chisana River. A brief statement of the geologic results of this work, accompanied by a topographic map, was made by Schrader[2] and furnished a groundwork of information for the later investigators.

The writer,[3] in association with Adolph Knopf and S. R. Capps, geologists, made a geologic reconnaissance of the Nabesna-White River district in 1908 and published a report that describes part of the area covered by the present report. These two reports were for a long time the chief sources of information regarding the district.

[1] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits on the upper White and Tanana Rivers: U. S. Geol. Survey 21st Ann. Rept., pt. 2, pp. 333–391, 1900.

[2] Mendenhall, W. C. and Schrader, F. C., The mineral resources of the Mount Wrangell district, Alaska: U. S. Geol. Survey Prof. Paper 15, pp. 33–45, 1903.

[3] Moffit, F. H. and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, 64 pp., 1910.

However, the discovery of placer gold on Bonanza Creek in the Chisana district made necessary a more thorough examination of the area, and in 1914, after the first rush of the stampeders had given place to systematic exploration of the gold-bearing gravels, topographic and geologic surveys by C. E. Griffin, topographer, and S. R. Capps,[4] geologist, were undertaken in the Chisana-White River district. Some parts of these surveys are included in the present report. In particular the geologic mapping by Capps covering the vicinity of the placer mines is reproduced practically as it was shown on the geologic reconnaissance map that accompanies his report, for without further detailed study little can be added to what is already given there.

PRESENT INVESTIGATION

The principal area of geologic investigation in 1940, among those previously unsurveyed, is on the northeast side of the Nutzotin Mountains, between the Chisana River and the international boundary. It is drained chiefly by the headwater tributaries of the Snag River. However, the field work of the Geological Survey party in 1940 covered more than this area, for part of the time was devoted to a review and extension of geologic mapping in the area between the Nabesna and Chisana Rivers, where special attention was given to the valleys of Cooper, Notch, and Cross Creeks, as they were recognized as places deserving critical study. At the close of the season R. G. Wayland, who assisted the writer in the more general investigation to which the summer was chiefly devoted, spent 19 days in a study of the occurrence of gold at the Nabesna mine. This was made possible through the hearty cooperation of Mr. C. F. Whitham, the discoverer of the ore body and the manager in charge of mining operations. An account of this work is given on pages 175–195.

The field party that was organized to carry out the primary undertaking of the season consisted of R. G. Wayland, junior geologist, Ira Morgridge and W. E. Van Hoose, packers, Barney Dawson, cook, and the writer, who was in charge of the party. The party was equipped with 14 horses and the necessary camp gear and food supplies. The time during which the surveys were in progress began June 5 and ended September 9, covering a period of 97 days. Fortunately for the Geological Survey party the weather conditions during most of the season were favorable to its work, although the exceptional deficiency of rain was a great misfortune to the placer miners of the Chisana district and materially reduced the production of gold from

[4] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, 130 pp., 1916.

that camp. Most of the season was given to the study of the geology of the eastern part of the district, which is a mineralized area that merited special examinations. Furthermore, it was hoped that the solution of several perplexing geologic problems would be found there, and it was felt that the remoteness of that section made improbable reexamination of it in the near future.

The work of the season was in continuation of a program of investigation of the eastern part of the Alaska Range, which has been in progress for several years.

GEOGRAPHY

RELIEF AND DRAINAGE

The Nutzotin Mountains form the eastern end of the Alaska Range, a great system of mountains that is one of the major physiographic features of the territory. Although it is difficult to give precise limits to the Nutzotin Mountains, they may be considered geologically to extend southeastward from the vicinity of Mentasta Pass or Suslota Pass and the Little Tok River to the international boundary, where they either cease to exist as a structural unit or merge with the Chugach Mountains and become part of the Saint Elias Range. The angle between the two mountain chains is occupied by the Wrangell group of mountains, which is in large part of volcanic origin. This group lies southwest of the area under consideration. The southeastern part of the Nutzotin Mountains is bordered on the northeast by the wide, swampy lowlands of the Tanana Valley and is crossed by two large streams, the Nabesna and Chisana Rivers, which are about 25 miles apart. They originate in huge glaciers within the Wrangell Mountain area and flow northeastward in steep-walled valleys through the Nutzotin Mountains, finally uniting to form the Tanana River. Farther south is a third river, the White, which is outside the area shown on the map and is tributary to the Yukon River rather than the Tanana. Its head is approximately 25 miles from the head of the Chisana River, and its course is east instead of northeast as far as the international boundary.

The next largest stream within the area is Beaver Creek, which rises in Beaver Lake, 12 miles east of Chisana Glacier, and flows eastward into Canadian territory. This is one of the few large streams that receive only a minor part of their water from melting glacier ice. Its tributary, the Snag River, drains much of the northeast side of the Nutzotin Mountains between the Chisana River and Beaver Creek. A large number of smaller streams, all of which are tributary to either the Tanana or the White River, make up the remainder of the drainage system. Many of them have glacial sources, which, however, are insignificant in size if compared with such masses of flowing ice as the Nabesna and Chisana Glaciers. Some of these streams, such as Bonanza and other neighboring creeks, are important for economic reasons, and some are known chiefly because their valleys furnish routes of travel.

The Nutzotin Mountains are physiographically youthful. They have been intensely glaciated in recent geologic time and still retain many small glaciers within their higher parts. Their outlines are rugged, suggesting not only the effects of rapid glacial erosion but also the character of the rocks that compose them. The highest peak of the Nutzotin Mountains within the area shown on the topographic map is Mount Allen, whose altitude is 9,487 feet, or more than 7,300 feet higher than the flood plain of the Chisana River 5 miles to the southeast and 7,300 feet higher than the Nabesna River at the mouth of Platinum Creek. The highest point of the mountains between upper Beaver Creek and the East Fork of the Snag River is 8,600 feet. When compared with the altitude of the forks of the Snag River, which is about 3,200 feet, this shows a difference of 5,400 feet. An examination of the topographic map will make it evident that peaks of 6,000 feet and even 7,000 feet are common throughout much of the district.

ROUTES AND TRAILS

The first prospectors to make their way into the Nutzotin Mountain area came through the Copper River Valley on the west and by the White River on the east. In August 1899, Brooks [5] and Peters met two of these prospectors, E. J. Cooper and H. A. Hammond, on Kletsan Creek, a tributary of the White River. They had come from the Copper River with horses and presumably were the first to bring a pack train through Cooper Pass.

Previous to 1914 some of the prospectors in the vicinity of the White River traveled trails from White Horse, in the Yukon Territory, or came through Skolai Pass from the Chitina Valley. Canadian maps [6] show as "James trail" the route by which William James, who with N. P. Nelson and others discovered placer gold on Bonanza Creek, made his way up Beaver Creek from the White River. Early prospectors in the Nabesna district usually followed the Copper River, just as the first prospectors had done.

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[5] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits on the upper White and Tanana Rivers: U. S. Geol. Survey, 21st Ann. Rept., pt. 2, 1900.

[6] D. D. Cairnes, Upper White River district, Yukon: Canada Geol. Survey, Mem. 50, map 123A, 1915.

After the Chisana mining camp was established, most of the travel in the district was between Chisana and McCarthy, on the Copper River Ry., in the Chitina Valley. In summer the usual route was through Skolai Pass and in winter over the Nizina and Chisana Glaciers.

At present much of the travel between Chisana and outside points is by airplane in both summer and winter. Mail and many of the supplies needed by the miners are carried by this means. Some freight, however, is still brought from Nabesna by horses in summer and by dog sled in winter. Nabesna is connected with the Richardson Highway by an automobile road and is therefore the most convenient point of entry to the Chisana district.

Within the district there are certain well-established routes of travel. The fairly well-defined depression between the Nutzotin Mountains and the Wrangell Mountains is the natural route for travel from the Copper River Valley to the heads of the Chisana and White Rivers. The trail through this depression leaves the Nabesna River at the old Indian village, about half a mile above the mouth of Cooper Creek, and ascends that creek to Cooper Pass, between Cooper and Notch Creeks, whence it follows Notch Creek to Cross Creek and the Chisana River. Cooper Pass, which has an altitude of 5,000 feet, is the highest ground crossed by the trail between the Copper and White Rivers. Because of this high altitude it is snowed in early in the fall and rarely is clear of drifts before the beginning of summer. It offers two routes for crossing the summit, the "summer trail," which keeps to the northeast of a prominent northwestward-trending mountain ridge, and the "winter trail," which swings around the southwest side of the ridge. The two trails are nearly parallel for about 8 miles and nowhere are more than 1½ miles apart. The winter trail has the easier grades but is not used in summer as the great number of granite boulders on the stream bars makes travel with horses difficult and dangerous. The summer trail necessitates a steep climb by south-bound travellers of more than 500 feet on the north side of the summit, and for more than 1 mile just north of the summit it follows a smooth mountain slope along the south side of a narrow lake where footing is uncertain because of the shallow soil and is especially treacherous if the trail is covered with snow.

This trail leads directly to the town of Chisana on Chathenda (Johnson) Creek, 2 miles east of the Chisana River and 7 miles from the mouth of Bonanza Creek. The distance by the trail and highway from Nabesna, mile 105 on the highway, to Chisana is slightly more than 48 miles. In following this trail it is necessary to ford the

Nabesna and Chisana Rivers, both of which are glacial streams and in times of high water are dangerous if not practically impassable. In addition to temporary high water the Chisana River offers the constant danger of quicksand to those unfamiliar with the crossing. No convenient camping places for parties traveling by pack train are available between the Nabesna River and "the big willows," which are on Notch Creek 8 miles above the junction of Notch and Cross Creeks, as most of this part of the trail is above timber line. Relief cabins on both sides of Cooper Pass, near the points where winter and summer trails join, have been built by the Alaska Road Commission.

From Chisana as center, trails radiate to various places. One leads to Bonanza Creek and the placer camps. The continuation of this trail is across a broad, barren flat to Beaver Creek and then to the practically deserted town of Horsfeld, 5 miles from the Canadian boundary. Timber is absent on this trail between Bonanza and Horsfeld, except for a small patch on the south side of Beaver Creek, near Klein Creek. From Horsfeld old trails lead southeastward down Beaver Creek to Ptarmigan Lake and the White River and northeastward to Baultoff Creek and a point on Beaver Creek near the international boundary. For 3½ miles this latter trail lies on the east side of the boundary but crosses back just below the mouth of Baultoff Creek, where Beaver Creek also swings back to the west side.

From Chisana a trail runs southward by way of the valleys of Bow Creek and Solo Creek to the White River and Skolai Pass and so to the Nizina River and the town of McCarthy, in the Chitina Valley. A trail from Chisana down the Chisana River was formerly in use but has been traveled so little in recent years that it is now almost obliterated. This is true also of the old Indian trail down the south bank of the Nabesna River.

TIMBER AND FORAGE

The Nutzotin Mountain area has the same kind of timber cover that is common elsewhere in southern interior Alaska. This cover consists chiefly of spruce but includes a minor proportion of deciduous trees, such as balsam poplar and aspen, which appear where soil and drainage conditions are favorable. Willows large enough for firewood and tent poles grow along many stream courses but have practically disappeared where camping has been frequent on some of the streams above the altitude of spruce. Carl and Klein Creeks are such places and consequently afford only a scanty supply of firewood to campers between Bonanza and Horsfeld, for this stretch of trail is above 4,000 feet, or above timber line for spruce. In general the timber line is below 4,000 feet, but it is variable and is considerably higher in places. On the north side of the head of Baultoff Creek Valley it reaches 5,000 feet, probably because of the southern exposure and protection from winter winds.

The largest and best timber grows along the stream courses and on the lower mountain slopes where drainage is good. It is suitable for local needs but probably will never be valuable for lumber in a wider market. Spruce that grows on the wet lowland areas is scrubby and of little value for anything but firewood. Many prospectors believe that it is better to burn some of these areas so as to give the ground a chance to dry and the grass to grow. Without doubt this has been the source of many fires in former years.

Feed for stock is locally abundant but cannot always be found where it is needed. It includes different varieties of grass; several of the vetches or "pea vines;" members of the horsetail family, sometimes referred to as goosegrass and rushes; the leaves of certain willows; and other less common plants. The best and most abundant feed for horses is usually found on the wide timberless bars of the larger streams or in the upper parts of the more-open tributary valleys near or just above the timber line. Horses like to feed in such places, because the breeze helps them in fighting the mosquitoes and flies.

The different forage plants have their own seasons, which may vary somewhat in time. Perhaps the earliest grass to come in the spring is the kind of bunchgrass that grows in low, swampy areas. The tender white new growth at the base of the old dry blades is relished by horses that have fed all winter on the dry forage of the river bars. However, another bunchgrass that grows best on the well-drained gravel benches is a more useful variety, for it furnishes forage in winter as well as in summer.

The tall redtop grass that grows so luxuriantly on the southern coast does not flourish so well in this district, yet is an important forage plant. The horsetails and pea vines are both excellent feed in their seasons, and the willows oftentimes take the place of the other forage plants.

Certain parts of the district support stock in both winter and summer. They are places where either the snow does not become so deep that horses cannot dig out the feed or where the wind keeps the ground bare. The bars of the Nabesna River illustrate both these conditions, and they have supported from 25 to 30 horses in winter for many years. The gravel benches near Horsfeld also furnish winter forage for stock. They are grown over with bunchgrass, scattered through the dwarf birch or buckbrush, which provides fine pasturage in summer and has supported a few horses practically every winter since the Chisana rush. In the early days of Horsfeld, when many horses were required for transporting supplies to the mining camps, it was the practice to burn over the benches in early spring before the new growth of grass was started and thus keep down the buckbrush. More recently this practice has not been followed, and the brush has gained on the grass in the competition for space.

Vegetation is controlled in part by the amount and distribution of rainfall and snow, as well as other factors, such as temperature and altitude. Official weather records for the district are not at hand, and only general information regarding the climate, such as is obtained by personal observation or from local inhabitants, can be given. Most of central Alaska has a semiarid climate, and the Nutzotin Mountain area is not an exception in this respect. The mean annual precipitation appears to be greater than in the Yukon-Tanana Valley, lower down, yet probably does not exceed 20 inches and may be considerably less. The monthly precipitation reaches its maximum in July and August. This is in favorable accord with the requirement of placer mining operations. In most years the miners of Bonanza Creek and the neighboring streams have a sufficient although not an excessive supply of water for their needs, but in 1940 most of them were obliged to close down their regular operations for approximately 6 weeks after the Fourth of July because of scanty rainfall and the resulting shortage of water for sluicing. Snow may fall in any month of the year, and at least one light snowfall sometime during the summer months is commonly expected. These unseasonable snows are not accompanied by low temperatures and disappear quickly.

The yearly range of temperature appears to be smaller than would be expected. Capps [7] gives a table of temperature observations that were made by H. H. Fields on Wilson Creek, Chisana district, in 1913–14. The readings were made at 7 o'clock in the morning and cover a period of 1 year 28 days. They show a range of −19° to 60° F. but undoubtedly would show higher temperatures if mid-day readings had been made. Probably a range of −40° to 85° F. would be more in accord with the temperature range of the district as a whole. It is usual for those unfamiliar with the climate of Alaska to think of it as particularly unfavorable, especially with respect to temperature, when in fact a wide range of conditions exist, and even in the interior, where the cold is greatest and continues longest, the winters are probably little more trying for people accustomed to them than they are in the northern United States. The long winters and brief summers might be expected to interfere seriously with

[7] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, p. 18, 1916.

plant life, but the many hours of summer daylight make up in part for the shortness of the summer season and enable the native plants to complete their annual growth quickly. Flowers are remarkable for their abundance and variety. They appear almost as soon as the snow goes in the spring, seeming to be pressed with the necessity of blooming as quickly as possible, and then disappear as suddenly as they came.

The growing season is roughly from May to September and fixes the time when work horses can be used without providing them with feed additional to that which they can be expected to get readily for themselves. These limits are not definite but vary considerably from season to season.

GEOLOGY

SYNOPSIS OF GEOLOGIC FORMATIONS

The rocks of the Nutzotin Mountains and the adjacent areas to be considered in this report consist dominantly of sedimentary beds, more or less folded and faulted but unmetamorphosed, or only slightly metamorphosed, among which shale, argillite, sandstone, arkose, graywacke, and conglomerate are the prevailing varieties. Limestone is subordinate to the other sedimentary rocks, although conspicuous in some localities because of its contrasting lighter color. These bedded sedimentary rocks and subordinate volcanic formations associated with them in places, including also a small area of schistose rocks and phyllites on the northern border of the area occupied by the younger beds, range in age from Middle Devonian or pre-middle Devonian, through Permian, Upper Triassic, Upper Jurassic, Lower and Upper Cretaceous, and Tertiary to Quaternary.

Although sedimentary rocks dominate, igneous rocks are widely distributed throughout the area and occur as the base on which the younger sediments were deposited as flows interbedded with sedimentary beds and as intrusives. They include dark amygdaloidal, basaltic, and andesitic lavas and intrusive masses, associated agglomerates and tuff beds, and granular intrusives of considerable variety but of prevailingly granodioritic character, which occur as batholiths, stocks, dikes, and sills.

The bedded basaltic and andesitic rocks are characteristic of the beginning and the end of the time range that applies to the sedimentary beds, for although they are practically absent among the Mesozoic deposits they constitute a large part of the Devonian and Permian formations and are represented by thick accumulations of volcanic flows in the areas covered by the Tertiary and more recent lavas.

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The youngest deposits of the region are for the most part the unconsolidated deposits laid down by streams and standing water and the unsorted morainal material deposited by ice, yet other unconsolidated accumulations of fragmental rock, such as waste on the hill slopes and volcanic ash, are to be included with these.

The following section gives the important features of the stratigraphic column so far as it is known:

Quaternary:
- Gravels, morainal material, and other unconsolidated deposits.
- Volcanic rocks.

Tertiary:
- Volcanic rocks.
- Deeply weathered, unconsolidated gravel deposits, with lignitized wood fragments.

Upper Cretaceous: Sandstones, shales, conglomerates, and tuffs.

Upper Jurassic and Lower Cretaceous: Shales, slates, sandstones, arkoses, graywackes, conglomerates, limestone, and tuffaceous beds. Banding or varving is common in the darker and finer grained beds.

Upper Jurassic (?): Sandy shale and massive, coarse conglomerate.

Upper Triassic: Limestone and shale.

Permian: Shale, sandstone, arkose, conglomerate, and limestone, associated with a much larger proportion of volcanic rocks.

Middle and Upper (?) Devonian: Lavas and pyroclastic beds, with considerable black shale.

Devonian or older: Schists and phyllites, with many intrusive bodies of granodioritic and more basic igneous rocks.

All the consolidated formations, including both the sedimentary deposits and the bedded volcanics, are intruded by igneous rocks. These range in composition from granite to gabbro and in texture from coarsely crystalline to densely fine-grained without recognizable mineral components. The times of intrusion are known only within wide limits, but the intrusives probably represent periods of Paleozoic as well as Mesozoic igneous activity. However, the most prominent and extensively developed of the granitic intrusives are regarded as of Mesozoic age.

The different geologic formations that have been distinguished in the field work are represented on the geologic map (pl. 2). This map incorporates some material that has been published in earlier reports, notably the report on the work done by Capps in 1914, as well as the results of the field studies by the writers of the present report. In addition, the writers have made free use of the field notes taken by F. C. Schrader in 1902 to extend the map so as to cover areas at the head of the Nabesna and Jacksina Rivers that were not visited by them in 1940.

PALEOZOIC OR PRE-PALEOZOIC ROCKS

The oldest rocks represented on the geologic map (pl. 2) are metamorphic crystalline rocks that crop out along the northeast side of the Nutzotin Mountains between the Beaver and Snag Rivers and farther north in the adjacent isolated hills south of the Snag River. They appear to be much-altered sedimentary deposits, which are intimately intruded by igneous rocks that are themselves more or less altered. They include gray phyllite, cherty and talcose-banded phyllite, silicified schist, schistose limestone, brown biotite schist, dark hornblende schist, gabbro, granodiorite, and granite gneiss. They form the lone mountain north of Carden Lake and the low, rounded hills between this mountain and the Nutzotin Mountains, as well as a narrow strip along the base of the Nutzotin Mountains, but whether they have a wide distribution remains to be learned. They are not known to crop out along the mountain front between the Chisana and Nabesna Rivers, although their presence there might be expected.

As their metamorphism would suggest, they are much folded and faulted and have a complex structure. Fossils were not found in them, and the only clue to their age is the degree of their alteration, which is plainly much greater than that of the slate and arkose of the Nutzotin Mountains adjacent to them on the southwest.

Wellesley Mountain is only a few miles north of the Snag River, at the place where that stream flows around the north side of the Carden Lake Hills. Brooks[8] found this isolated mountain to be made up of a massive conglomerate, in which beds of clay slate are included, and an overlying part consisting almost entirely of clay slates. He believed the whole assemblage to be between 1,000 and 2,000 feet thick and of Devonian or Carboniferous age, as suggested by a few fossils from a slate bed in the conglomerate.

At a later time Mertie[9] presented reasons for regarding the Wellesley formation as Mississippian rather than Devonian, but stated that his reasons were not conclusive. It therefore seems necessary to withhold final judgment on the age of these beds till more evidence is obtained.

As seen from the south, Wellesley Mountain appears to contain one, or possibly two, thick beds of limestone in addition to the conglomerate and slate mentioned by Brooks. The limestone crops out along the lower south slope of the mountain and is in the strike of the Devonian limestone beds north of the Nabesna River, so that

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[8] Brooks, A. H., A reconnaissance in the White and Tanana River basins, Alaska, in 1898: U. S. Geol. Survey 20th Ann. Rept., pt. 7, pp. 431-494, 1900.

[9] Mertie, J. B., Jr., A geologic reconnaissance of the Dennison Fork district, Alaska: U. S. Geol. Survey Bull. 827, p. 26, 1931.

a correlation of the beds of these localities is immediately suggested. However, Brooks' description of the rocks of Wellesley Mountain seems to indicate that they are less metamorphosed than the schist, phyllite, and other crystalline rocks of the Nutzotin Mountain area. On the other hand, the Devonian limestone north of the Nabesna River is associated with schistose rocks. Although the limestones of the two localities may be of the same age, the associated rocks do not suggest correlation on lithologic grounds. Correlation of the crystalline rocks of the Nutzotin area with the conglomerate and slate of Wellesley Mountain seems even less probable. The conclusion therefore appears to be that the crystalline rocks, except possibly some of the intrusives, are not younger than the rocks of Wellesley Mountain (Devonian or Carboniferous) and probably are older.

PALEOZOIC ROCKS

DEVONIAN AND PERMIAN ROCKS

CHARACTER AND DISTRIBUTION

The rocks represented on the geologic map as Paleozoic include a variety of fossiliferous sedimentary beds associated with interstratified volcanic deposits and intrusives. Some of them contain a sparse fauna, which has been identified as Middle Devonian. Other apparently similar rocks have yielded a large and distinctive Permian fauna. These two groups are not of equal geologic importance. The area of Permian beds is much greater than that of the known Devonian beds and extends northwestward and southeastward along the Alaska Range, the Wrangell Mountains, and the Saint Elias Range far beyond the limits of the district under consideration. Thus far the distinction between the two groups has been made solely on the evidence of fossils, but the information now at hand is insufficient to make possible a separation of Devonian and Permian rocks in some parts of the area. These rocks therefore are represented as a single formation in such places. Without doubt the larger areas thus designated and Permian areas as well include masses of infolded or infaulted Mesozoic beds that were not seen or recognized in the course of reconnaissance mapping.

Devonian rocks have been recognized at only one place within the area shown on the geologic map, that is, on Bonanza Creek, near the mouth of Little Eldorado Creek. At that locality Capps [10] collected Middle Devonian fossils from an assemblage of rocks that include "basic lavas, agglomerates, and tuffs, associated with considerable black shale and minor amounts of graywacke." These rocks appear

[10] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, p. 31, 1916.

to lie conformably beneath the Permian lavas and pyroclastic rocks of lower Bonanza Creek. Lithologically the two groups are so similar that the difference in their ages was not suspected and did not become known till after the identity of the Devonian fossils had been established. However, although there is uncertainty about the distribution and amount of the Devonian rocks, which cannot be cleared up without further detailed investigation, it does not seem probable that they make up a large proportion of the Paleozoic rocks in the area that includes Chathenda (Johnson) Creek and the headwaters of Beaver Creek, where the fossils were obtained.

The Permian stratigraphic section, like the Devonian section, comprises both igneous and sedimentary rocks. As has been stated, a part or parts of the two sections are so similar lithologically that they cannot be distinguished where fossils are not found, yet the Permian section as a whole shows a much greater variety among its members than the Devonian is known to have. The sedimentary members include massive limestone, thin-bedded limestone, shale, arkose, banded shale and arkose, sandstone, grit, and conglomerate. These bedded members are intruded by basic and acidic igneous rocks. They are folded and faulted but are not schistose, except locally and from causes that did not affect the group as a whole.

The Permian beds are exposed in two principal areas. The larger area extends from Jack Creek to the Chisana River and adjoins the Mesozoic area of the Nutzotin Mountains on the northeast, along a boundary line that follows approximately the valleys of Totschunda, Cooper, and Notch Creeks. On the southwest the Permian rocks are concealed by snow and ice and the lava flows of the Wrangell Mountains, so that their extent in that direction is not known.

The second area of Permian beds extends northwestward from the international boundary near Baultoff and Eureka Creeks to the Snag River. This area lies between a great mass of intrusive granite on one side and a ridge of younger slate and arkose on the other and presents many difficult problems of structure and stratigraphy. Between the two Permian areas lies the area of undifferentiated Devonian and Permian rocks, which probably is dominantly Permian.

Basic igneous rocks, consisting largely of amygdaloidal lava flows presumably belonging to the lower part of the group as exposed in this district, comprise the Permian rocks adjacent to the Mesozoic shale and arkose. They extend from Totschunda Creek to the Chisana River and form an unknown proportion of the rocks north of Beaver Lake and around the headwaters of Beaver Creek. Locally, bodies of massive, coarsely crystalline limestone are included in the lava flows near the boundary. In addition, the lava flows are cut by granite intrusives, which, together with the lava flows, are described in another part of this paper. The sedimentary members of the group, with the exception of the massive limestone masses just mentioned, appear in the high mountains between the valleys of Cooper and Notch Creeks and the Nabesna River and Glacier.

Cross Creek has cut a deep, narrow valley at right angles to the general trend of the Permian beds and thereby has furnished one of the best localities in the district for studying the relations of the beds. The most conspicuous feature of the valley walls is a limestone formation, which appears on both sides of the valley and rises gradually from the creek level near the entrance of the valley to the mountain tops around the Cross Creek Glacier. Approximately 1,200 feet of sedimentary deposits, including graywacke, arkose, shale, and thick beds of conglomerate, underlies the limestone, and from 1,000 to 1,500 feet of shale rests on it. All these beds were intruded by basaltic rocks in the form of thick irregular sills and dikes, with the result that different members of the group are offset by numerous strong faults and are separated from one another by basaltic bodies that might be mistaken for flows. This effect is especially noticeable in the alinement of the limestone and at first gives rise to the impression that several beds of limestone are present, which are separated because of the outpouring of lavas during the time of their deposition.

A generalized section of the Permian sedimentary beds on the north side of Cross Creek is shown on plate 3.

A section of the beds at a gulch 2½ miles below the moraine of the glacier is represented. The important things to notice are the thickness of the limestone, which is approximately 250 feet, and the fact that part of the section above the limestone resembles lithologically the banded Mesozoic slate and arkose described on page 125. The basalt at the base of the section may be an intruded mass or possibly one of the underlying lava flows. A section of the beds south of Cross Creek would show more of the intruded basaltic rocks than appear on the north side.

Although much faulted, the Permian beds on Cross Creek are not closely folded, and the metamorphism they show to the unaided eye is chiefly that produced by the intrusion of igneous rocks, especially the partial recrystallization of limestone beds.

The rocks included in the part of the Permian area crossed by the Nabesna River are less favorably exposed for study than those on Cross Creek. Except for one small area of limestone on Platinum Creek, all the rocks mapped as Permian north of the river are basic igneous rocks. South of the Nabesna River Permian sedimentary beds are exposed in the narrow valley of Camp Creek. They include limestone beds and limy shale or tuff, argillite, slate, conglomerate, basaltic igneous rocks, some of which are amygdaloidal, and various intrusive rocks. A slightly iron-stained, coarse, shaly rock contains a few scattered fragments of wood that have been altered to coaly material. Many large boulders of massive conglomerate lie in the creek bed. Pieces of conglomerate made up of well-rounded pebbles of milky quartz and black argillite are also present. The pebbles show much uniformity of size and average less than 2 inches in diameter. Their contrasting colors makes them stand out from the creek wash. The limestone and limy shale beds contain many Permian fossils, but the beds with coal fragments and the conglomerate and banded argillite and slate boulders suggest that the assemblage includes some beds of Mesozoic sediments. When viewed from the north side of the Nabesna River, the beds of the high mountains around Camp Creek appear to be little folded and to dip moderately toward the west. As may be seen from the geologic map, some remnants of Mesozoic beds that formerly covered the Permian rocks remain in the upper parts of the mountains.

The Permian rocks in the vicinity of Chathenda (Johnson) Creek appear to be made up chiefly of basic igneous members essentially like the Middle Devonian rocks with which they are associated. They are separated from the Permian area on the west by overlying gravel deposits and from those on the east by a great granite batholith and by overlying beds of Mesozoic slate and sandstone. They are believed to represent the earliest of the Permian formations, because they are associated with Devonian rocks.

The Permian rocks exposed on the Snag River, Baultoff Creek, and neighboring streams do not resemble closely the Permian beds of Cross Creek. They include basaltic and andesitic rocks, part of which are amygdaloidal, crystalline limestone, sandy limestone, limy arkose, hard gray sandstone, quartzite, soft black-banded argillite, thinly-banded cherty beds, grit, conglomerate, and tuff. They are exposed in a narrow belt extending northwestward from the international boundary to the Snag River and are best seen in Baultoff Creek Valley and the mountains southwest of the East Fork of the Snag River. The Permian beds, including the volcanic members, are much folded and faulted. They were intruded by granitic rocks of different kinds and in places have been much altered by the intrusions, as is shown by the recrystallization of the limestone and the silicification of the banded argillites and the limestone. The Permian rocks are overlain, probably unconformably, by Mesozoic beds, which are folded and faulted into the older rocks and now appear as bands and small isolated areas within the part occupied by them. In places the similarity between some members of the Paleozoic and

Mesozoic sequences is such that it is difficult to distinguish them from one another where fossils are lacking. This is especially true of the limestone and the banded slate-argillite or slate-sandstone members.

An attempt was made at different places on Baultoff Creek to obtain a measured section as large as possible and made up dominantly of the sedimentary members of the Permian rocks rather than the volcanic members. Such a section is represented on plate 4, which is given principally to show the diversity of character of the beds at one locality and is not presented as a complete stratigraphic section of the Permian sedimentary beds of the district.

A satisfactory stratigraphic section of the Permian rocks of the Chisana and Nabesna districts has not yet been worked out. Probably such a section does not exist at any place and if it does would not represent in detail the conditions in other places. Yet some of the characteristics of the section are known. The generalized section for the Chisana-White River district as interpreted by Capps[11] is given here, rearranged so that the oldest rocks appear at the bottom of the column.

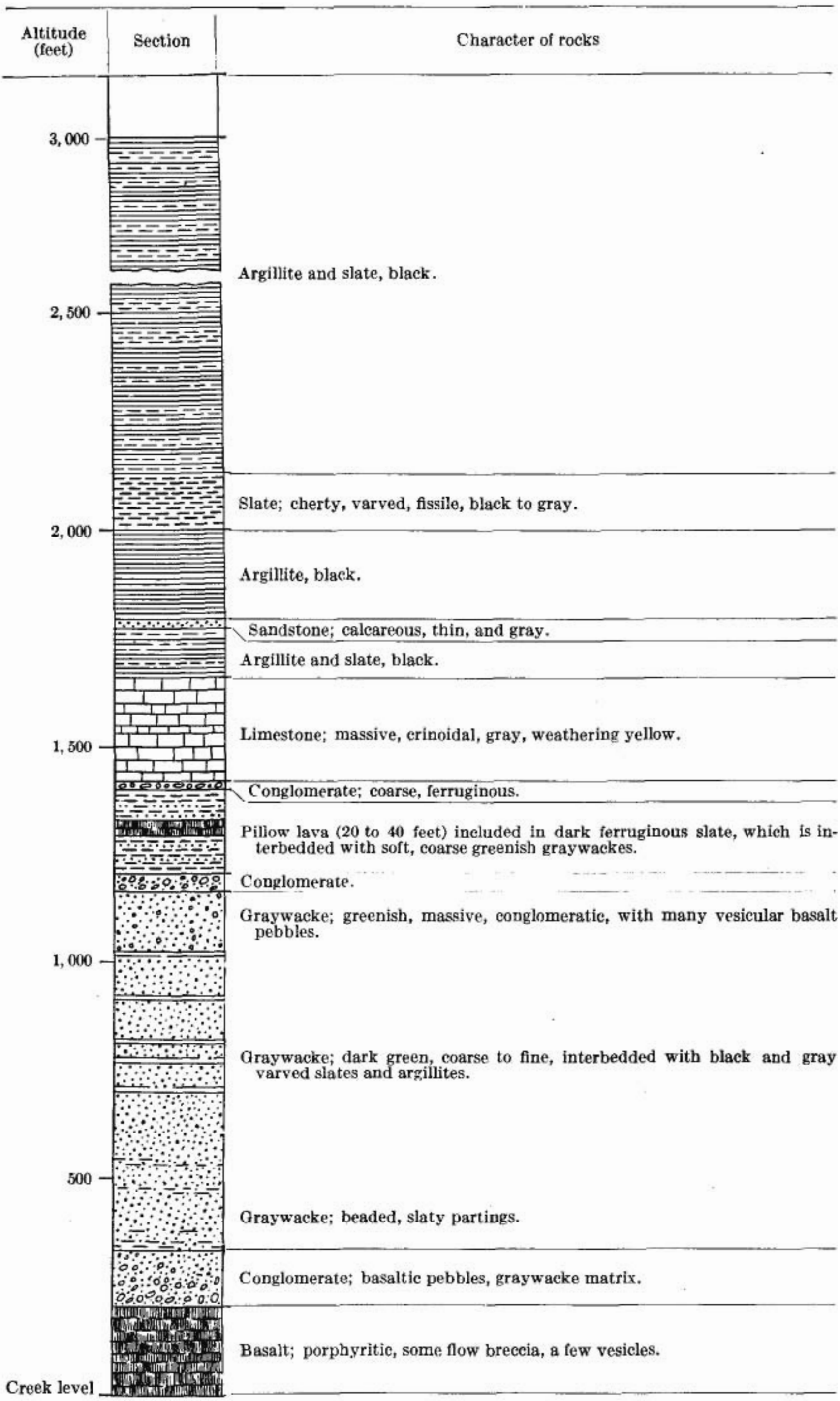
1. Basic bedded lavas, with little sedimentary material.
2. Massive limestone beds of Skolai Creek, with interbedded lavas and minor amounts of shale and conglomerate.
3. Lavas and pyroclastic rocks, with small amounts of sediments.
4. Massive limestone, associated with shales, thin-bedded limestones, and a little sandstone and conglomerate.
5. Lavas and pyroclastic beds, with some shales.

This section, which represents many thousands of feet of bedded deposits, is based on observations in the vicinity of Skolai Creek and the Nizina Glacier, where the upper part of the section is recognized. The Permian rocks of the Chathenda (Johnson) Creek area are regarded as being low in the section. This presumption rests on the fact that they are associated with Devonian sediments. In other localities, as on Cross Creek and the Nabesna River, a higher part of the section may be represented. It is necessary to keep in mind, however, that a stratigraphic section that is based on conditions in the White and Nizina River Valleys may not represent the conditions so far away as the Chisana and Nabesna Rivers, where beds corresponding to those of the southern area have not been recognized.

AGE AND CORRELATION

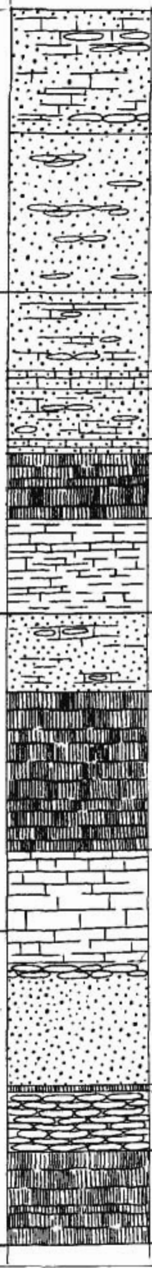
The age assignment of the rocks that have been described as belonging to the Permian period is made on the evidence of numerous fossils, which have been collected by the various investigators

[11] Capps, S. R., op. cit. p. 39.



GENERALIZED SECTION OF THE PERMIAN BEDS ON THE NORTH SIDE OF CROSS CREEK.

Measurements are based partly on barometric readings and partly on estimates.



Altitude (feet)	Thickness (feet)	Character of rocks
		Massive limy, arkosic beds with a few thin, black cherty partings; cliff-forming, yellowish-weathering, and tuffaceous (?).
	50	Arkosic beds with thin cherty partings.
5,300		
	25	Arkosic and black cherty beds with limestone layers as much as 12 inches thick.
	4–5	Sandy limestone; fossiliferous.
		Limy arkosic beds interbedded with hard cherty slate.
	4	Sandy limestone.
	20	Basalt.
	30	Thin limy and hard slaty parts.
5,200		
	25	Black and gray banded cherty beds, limy sandstone; fossiliferous.
	50	Basalt.
		Limy beds.
5,100		
	75	Hard banded cherty beds.
		Arkosic beds.
	6	Basalt.
	20	Banded cherty beds.
	30	Basalt.
5,000	Creek level	

SECTION OF PART OF THE SEDIMENTARY MEMBERS OF THE PERMIAN ROCKS ON BAULTOFF CREEK, ABOUT 4 MILES SOUTHEAST OF THE PASS TO EAST FORK.

Thicknesses given are from barometric readings and estimates.

who have worked in this and neighboring fields. The collections that were made in 1940 have been examined by the paleontologists and will be listed in a future paper. They will be referred to the Permian period, however, for in the publications of the Geological Survey the Permian has now been given the standing of a separate period rather than an epoch of the Carboniferous.

As has been stated before, the Permian rocks exposed in the Nabesna and Chisana districts occupy an intermediate position in a belt of Permian deposits that has been identified on the south side of the Alaska Range from the Delta River to the White River. This belt continues along the north border of the St. Elias Range into Canadian territory and through Skolai Pass to the head of the Nizina River. Its boundaries are not yet definitely known.

Permian rocks are widely distributed in Alaska and have two outstanding characteristics; they have yielded a fauna that is more closely related to that of Asia than to that of most of North America, and in many places they include a large proportion of volcanic deposits.

One of the best-known sections of Permian rocks in Alaska is exposed on the Yukon River, just above the mouth of the Nation River, and is referred to here for the purpose of comparison. It consists essentially of limestone and has yielded a large Permian fauna. A section measured by Mertie [12] gave a minimum thickness of 527 feet for the formation, of which 373 feet is limestone. However, the top of the section was not recognized, and the figures may represent the thickness of only a part of the original section. The formation was given the name Tahkandit limestone.

MESOZOIC ROCKS

GENERAL FEATURES

The Mesozoic rocks of the district have not yet been studied sufficiently to make possible a complete differentiation of the various members of the group. Moreover, such a differentiation could not be easily carried out, for the lithologic similarity of the beds and the scarcity of fossils in all but a few of them make it difficult to distinguish the deposits of different epochs and would require much time for its accomplishment.

The rocks are dominantly marine sediments and in contrast with the Permian formations are notably lacking in interbedded volcanic members, although they include beds that the microscope shows contain volcanic dust fragments and are cut by intrusive igneous rocks.

[12] Mertie, J. B., Jr., The Yukon-Tanana region, Alaska: U. S. Geol. Survey Bull. 872, pp. 146–153, 1937.

Limestone, shale or slate, argillite, arkose, graywacke, sandstone, grit, and conglomerate are the prevailing varieties. Sediments of Upper Triassic, Upper Jurassic, Lower Cretaceous, and Upper Cretaceous age have been recognized among them. The two outstanding characteristics of the Mesozoic rocks are that they are dominantly argillaceous and arenaceous rather than calcareous and that much the greater part of them, namely the Upper Jurassic and Lower Cretaceous deposits, were derived from rapidly alternating thin beds of mud and fine sand now altered to slate, argillite, and sandstone or quartzite. These rocks make up most of the Nutzotin Mountains and will be described together, as they have not yet been differentiated.

The Upper Triassic limestone and the Upper Cretaceous sandstones are relatively less important with respect to volume and area than the beds of intermediate age and are readily recognized.

UPPER TRIASSIC ROCKS

CHARACTER AND DISTRIBUTION

The known Triassic rocks of the district include many small, widely distributed areas of limestone and a single area of limy arkose and shale whose relation to the limestone is not yet proved, although the shale probably is younger.

The limestone consists of two parts—a lower member composed of thick beds and an upper member made up of thin beds separated by shale partings. In general the Upper Triassic limestone is less distinctly crystalline than the Permian limestone, except where it is intruded by igneous rock.

The arkose or shaly part of the Triassic rocks is not readily distinguished from some of the younger Mesozoic beds without the aid of fossils and may turn out eventually to be more widely distributed than is now realized. These rocks and the limestone were not seen in contact with each other, and their stratigraphic relations therefore are still open to question.

Practically all of the post-Permian limestone deposits of the district are of Upper Triassic age, although a few thin beds of limestone have been found interstratified with the overlying slates and their associated sandy beds. The Upper Triassic limestone may be divided into a basal part, made up of thick beds, and an upper part, which consists of thin beds and a small proportion of shale. This limestone is exposed north of the Nabesna River at White Mountain, where Schrader [13] gave it the name Nabesna limestone, in the vicinity of Cooper Pass, and in the valleys of the Snag River and possibly of Baultoff Creek. The best exposures are at White Mountain and in

[13] Mendenhall, W. C. and Schrader, F. C., The mineral resources of the Mount Wrangell district, Alaska: U. S. Geol. Survey Prof. Paper 15, p. 34, 1903.

the low hills, locally known as the Raven Hills, between Jack Creek and the lower part of the Jacksina River. The Nabesna gold mine is in the limestone of White Mountain. At this place the formation consists of 1,200 feet of massive, light gray, dense or crystalline limestone and about 800 feet of overlying thin-bedded light gray limestone. The thin-bedded limestone consists of beds that commonly do not exceed 6 inches in thickness, that are separated by thin shaly layers, and that are themselves less pure than the limestone of the thick underlying beds, probably containing a small proportion of argillaceous material. Near the Nabesna mine the limestone has been greatly altered by the intrusion of a mass of dioritic rock. At the Raven Hills only the lower massive part of the Upper Triassic limestone is exposed. Heretofore the limestone of this vicinity has been assigned with much hesitation to the Permian, as the nearest limestone of known age, on Platinum Creek, is Permian and the association of rocks is similar, but the work done in 1940 leaves little doubt that it is correctly assigned to the Upper Triassic.

The presence of Triassic limestone in Cooper Pass has been known since 1902, when Schrader [14] collected fossils there, but the presence of both Permian and Upper Triassic limestone was not discovered until later. The Upper Triassic limestone of Cooper Pass is well exposed in the ridge between the winter and summer trails. Both the massive beds and the upper thin-bedded part of the formation are present, so that the thickness of the beds exposed may be as great as that at White Mountain, although it is not known. The beds are much folded and faulted and in many places stand on end. Massive beds of the formation are exposed on the south side of Notch Creek, 5 miles southeast of the summit of Cooper Pass. They form a conspicuous ridge on the side of the valley, where they are faulted against amygdaloidal lava flows and are only a short distance from Permian limestone beds. The fault dips to the northeast and marks a zone of much disturbance, which affects both the limestone and the basalt. These amygdaloidal lavas are not only closely folded and faulted but are overturned toward the southwest as well. The Upper Triassic limestone of Cooper Pass and Notch Creek is differentiated from the nearby Permian limestone beds on the evidence afforded by fossils and by the degree of recrystallization, which in general is greater in the older beds.

The Upper Triassic limestone of the Snag River Valley appears in several small isolated areas in the mountains southwest of the East Fork. All the beds of which the age is definitely established on the evidence afforded by fossils, belong to the upper, thin-bedded part of the formation. Although massive beds of limestone crop

[14] Mendenhall, W. C., and Schrader, F. C., op. cit., p. 37.

out near the Upper Triassic limestone in places, they appear to belong among the older Permian beds. Limestone of unquestioned Upper Triassic age was not recognized in the valley of Baultoff Creek, but some thin beds that may prove to be Upper Triassic crop out southwest of the pass to the East Fork. Thin-bedded limestone that is abundantly fossiliferous is exposed on the principal western tributary of Crescent Creek, a local name for a southern tributary of the East Fork, 2½ miles from the pass to Baultoff Creek. They also crop out at the head of another southern tributary 1½ miles below Crescent Creek, and between the head of the Snag River and its largest tributary on the west. The age of all these deposits is known by the characteristic Upper Triassic fossil, *Monotis* (*Pseudomonotis*) *subcircularis* Gabb, which is abundant in places.

The irregular distribution of the limestone areas is notable and probably results from a number of causes, chief among which are folding and faulting combined with the removal of much of the original deposits by erosion. It is not clear why only the upper part of the limestone seems to be present in this locality. Possibly in some way this is the result of faulting, or it may be that the more massive lower beds never were deposited or were removed by erosion before the thin-bedded members were deposited, as has been suggested for the limestone of the Chitina Valley.[15] However, the evidence necessary to prove the existence of this suggested uncomformity does not yet seem sufficient.

Geologic investigations in the Nabesna and Chisana districts have shown the occurrence of shale or arkose comparable to the McCarthy shale overlying the Upper Triassic limestone of the Chitina Valley at only one locality. This locality is the mountain between the branches of the Snag River, and it shows a narrow belt of coarse, arkosic and limy beds enclosed by areas of Permian volcanics. The belt trends east and west and includes a considerable thickness of folded beds that yielded Upper Triassic fossils. Possibly several hundred feet of these deposits is present.

The occurrence of these clastic beds in such thickness suggests the possibility that corresponding beds may be present in other parts of the Mesozoic area, which have not been recognized because fossils for their identification were not found in them. On the other hand, the seeming absence of an Upper Triassic shale formation overlying the limestone may mean that although the shale was widely distributed most of it was removed by erosion before the Upper Jurassic beds were laid down.

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[15] Moffit, F. H., Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894, p. 51, 1938.

THICKNESS AND STRUCTURE

Measurements have already been given (p. 123) for the thickness of the Upper Triassic limestone at White Mountain. These measurements are 1,200 feet for the lower massive part of the formation and about 800 for the overlying thin-bedded part, a total of 2,000 feet. This is 1,000 feet less than the combined thickness of the Upper Triassic Chitistone and Nizina limestones of the Chitina Valley but may represent only part of the original thickness. However, these measurements are much greater than the known thickness at any other place in the district, for nowhere else, except at White Mountain, is such a large part of the limestone exposed in one section. In most places only a relatively small thickness of the beds now remains.

Any estimate of the thickness of the limy, arkosic beds of the Snag River locality is even less definite, as the beds there may be associated with younger Mesozoic deposits that were not differentiated from them. The thickness apparently is some hundreds of feet but probably is considerably less than that of the limestone.

Little can be said regarding the structure of the limestone other than that the beds in most places are much folded and faulted and are highly deformed compared with their original condition. Folding is especially prevalent in the thin-bedded part of the section, and exposures of the contorted strata are highly conspicuous. Yet at White Mountain and the Raven Hills the beds are not closely folded and are only moderately tilted.

As has been stated previously, the limestone was probably deposited unconformably on the Permian rocks and is overlain unconformably by younger Mesozoic beds.

The age assignment of the limestone is based on fossils collected from it at practically all exposures mapped as Upper Triassic, and although the number of species is small the assignment is not doubtful. On the other hand, the number of species collected from the arkosic beds of a single locality in the Snag River Valley is much larger than the number afforded by the limestone, and the fossils are equally diagnostic.

UPPER JURASSIC AND LOWER CRETACEOUS ROCKS

CHARACTER AND DISTRIBUTION

A brief description of the banded slate-argillite-sandstone beds of the Nutzotin Mountains has been given. For the most part the beds are consolidated and deformed marine sedimentary deposits, which accumulated in a sea of shallow or moderate depth where a regularly repeated and long continued alternation of the conditions of sedimentation produced a great thickness of strata that are notable for their varved or banded structure. The alternation may have been seasonal.

It was long continued, for the depth of the accumulation reached many hundreds of feet, possibly several thousand, and, although the accumulation may have been relatively rapid, much time was required for building up so great a thickness. Alternation in conditions of deposition took place with great regularity, as little variation in thickness of beds appears in any one exposure.

The thickness of the individual beds ranges from a fraction of an inch to many inches or feet, but in general the thickness of one bed in a given limited section is not greatly different from that of the adjoining bed. Thick beds of one kind of material separated by thin beds of the other are unusual. In much of the section the beds commonly occur in pairs made up of fine and coarse material or materials of contrasting color which grade into each other by a change in the size of grain or the composition but are distinctly separated from the adjoining pairs above and below. The banding or varving of some of the slate or slate-argillite beds is not apparent on a freshly broken surface but is pronounced on the weathered surface. This seems to indicate a slight difference in chemical composition of the beds. Some of the banding is due to increase in size of grain or to an increased proportion of fine quartz grains, so slight as hardly to be noticed without careful examination. However, as the beds become thicker the sandy layers grow coarser and gradation between beds is less distinct. Previous field work has shown that the width of the bands or the thickness of the beds is progressively greater as the belt of Mesozoic rocks is followed southeastward from the vicinity of Suslota Pass. Near the international boundary, zones of the banded argillaceous beds alternate with zones of brownish-weathering gray arkose and fine arkosic conglomerate or grit. These belts of fine and coarse sediments are measured in tens or hundreds of feet and are prominent in the mountains northeast of Baultoff Creek and the east fork of the Snag River.

Although the banded rocks are dominant, the stratigraphic section includes beds of conglomerate and grit and a few thin beds of limestone. The group forms a great synclinal trough extending from Beaver Creek to Suslota Pass, a distance of 85 miles, and reaching a width of approximately 15 miles in the widest part. The beds are folded and faulted but are not schistose.

Fossils are not plentiful in these banded beds but are locally present and are sufficient in number and diagnostic value to show that Upper Jurassic and Lower Cretaceous deposits are included in the section. However, as has been stated, the rocks belonging to these two epochs were not differentiated in the field work on the Nutzotin Mountains and are therefore represented as a single formation on the geologic map. Moreover, this formation may include unrecognized

Upper Triassic rocks. In a few places, as on Nabesna River, small areas of Upper Jurassic beds were identified by fossils where Lower Cretaceous beds are believed not to be present. These areas are shown as Upper Jurassic. Special attention is directed to one of them on Gravel Creek, as it has a bearing on the age of some of the igneous rocks. A small area of Upper Jurassic rocks is exposed on the north side of Gravel Creek, about 3 miles from its mouth. Graywacke or dark arkosic sandstone containing bivalve shells and coaly remains of plants crops out at the edge of the flood plain and is associated with a conglomerate bed, which appears on the mountain slope to the north, 200 to 300 feet higher than the creek bars. The conglomerate is massive and coarse, containing cobbles and boulders as much as 5 feet in diameter, which weather out readily. Most of the boulders are igneous, chiefly dark, fine-grained basaltic rocks and deeply weathered granodorite. Some of the smaller pebbles and cobbles are hard arkosic sandstone. The thickness of the conglomerate is nearly 75 feet, but the thickness of the graywacke was not determined, for the exposures are few and inadequate for making measurements. Furthermore, the stratigraphic relation of the conglomerate and graywacke was not determined, inasmuch as a contact of the two was not seen. The neighboring country rocks are altered basic igneous rocks of Permian age and granitic instrusives. Fossils were collected from the graywacke but not from the conglomerate. Unfortunately, the shells and plants collected from the beds are not fully diagnostic, although they are regarded by J. B. Reeside, who examined them, as probably Upper Jurassic. The particular interest of these beds is that they suggest an upper age limit for the granitic rocks of the vicinity.

UPPER CRETACEOUS ROCKS

CHARACTER AND DISTRIBUTION

Sandstone, sandy shale, and conglomerate containing pieces of lignitized wood and other plant remains make up the deposits that are here referred to the Upper Cretaceous epoch. Only three small areas of these beds are known to lie within the district represented on the map. One adjoins the Chisana Glacier. The other two are in the valley of Chathenda (Johnson) Creek or are adjacent to it and hitherto have been regarded as probably of Tertiary age but now are thought more probably to be Upper Cretaceous. The rocks of these three areas resemble one another lithologically but differ from the Upper Jurassic and Lower Cretaceous beds in being less firmly consolidated and less closely folded.

Outcrops of well-consolidated arkosic sandstone, of greenish-gray color but showing a yellowish or brownish weathered surface, form a series of ledges along the juncture of the Chisana River flood plain and the lower south slope of Euchre Mountain near the Chisana Glacier. The beds are thick and are separated by shaly partings. In places the texture suggests the presence of some tuffaceous material in them. Apparently between 400 and 500 feet of the sandstone is present in the lower slopes of Euchre Mountain, but the extent of the beds along the north side of the glacier was not determined, because the loose surface material and vegetation hide the rocks in that vicinity. A contact of the sandstone with the underlying Permian lavas was not seen, although float material from the basaltic rocks of the mountain above is abundant.

The beds are folded and show dips of as much as 50° NW. at the east margin of the area and of 20° E. near the glacier. These observations suggest a synclinal structure, with the axis of the syncline extending in a direction somewhat east of north.

Plant remains, most of which are fragmental, are abundant in some of the beds. Collections from them were submitted to R. W. Brown for identification and were determined by him to be of Upper Cretaceous age.

Two areas of dominantly arenaceous beds, which resemble those of Euchre Mountain, are found near the placer camp of Bonanza, one northeast of Beaver Lake, and the other between Rhyolite and Chathenda Creeks. They were described by Capps,[16] who collected fossil plants from them and tentatively assigned them to the Tertiary. He states that near Beaver Lake

> the lowest beds exposed consist of hard sandstones and fine conglomerates composed of small pebbles of quartz, slate, and various igneous rocks embedded in an arkosic matrix. Some shale, which on weathering quickly breaks down to soft mud, was seen, and thin layers of lignitic material 2 inches or less in thickness occur in places. Above these clastic beds of relatively fine materials there occurs a thick conglomerate, with some gritty sandstones. Some of the pebbles are a foot or more in diameter, and they are composed for the most part of igneous rocks such as are found in the Carboniferous [Permian] terranes of this district, including diorite, lavas, and pyroclastic materials, in an arkose matrix. The conglomerate covers an area of several square miles and forms prominent cliffs 200 feet or more in height. The beds have been mildly tilted, the general strike being a little west of north and the dips 5°–20° E.

Of the locality north of Rhyolite Creek Capps says:

> The formation there consists of conglomerates, sandstones, and shales, with some volcanic tuffs and interbedded basic lava flows. Some carbonaceous shales with thin beds of impure lignite are present, but no coal beds of workable thickness have been found. The beds form a synclinal trough, which is folded down into the older lavas and pyroclastic rocks and has an easterly strike.

The similarity between these beds of the Chathenda (Johnson) Creek Valley and the sandstones at Euchre Mountain suggested the possibility of their equivalence. This suggested correlation was con-

[16] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 52–53, 1916.

firmed by a re-examination of the evidence furnished by the earlier fossil collections. Accordingly the beds near Chathenda (Johnson) Creek as well as those at Euchre Mountain are represented on the map as Upper Cretaceous.

It has been stated that the Upper Cretaceous sandstone near Euchre Mountain is probably between 400 and 500 feet thick. The older Mesozoic formations are absent in this vicinity, so that the Upper Cretaceous beds rest unconformably on Permian basaltic rocks. Apparently the sandstone has the form of a broad syncline.

According to Capps,[17] the shales, arkosic sandstones, and conglomerate of Rocker Creek are at least 300 feet thick, and the similar beds east of Beaver Lake are not less than 1,000 feet thick, 200 feet of which is massive cliff-forming conglomerate. These beds, like those of Euchre Mountain, overlie the older Devonian and Permian rocks and have been folded and tilted with them in the movements of the late Mesozoic or post-Mesozoic mountain building. Probably the extent of the area occupied by Upper Cretaceous rocks was much greater at one time, and the thickness of the sandstone and conglomerate varied much in different places. The estimate of 1,000 feet for the thickness of the beds near Beaver Lake is not a maximum figure for the original deposits, for an unknown thickness has been eroded from the top in Tertiary and Cenozoic time.

The distribution and character of the Upper Cretaceous sediments and the common occurrence of the remains of land plants in them suggest, as was pointed out by Capps, that these beds are river valley or estuarine deposits rather than sediments laid down in the sea. Marine shells were not found in association with the plant remains of these rocks.

STRUCTURE AND THICKNESS OF THE MESOZOIC BEDS

The Mesozoic sedimentary beds of the Nutzotin Mountains lie unconformably on older rocks, some of which are of Middle Devonian and some of Permian age. They represent four different epochs in three geologic periods. Two of them, the Upper Triassic and the Upper Jurassic, are separated by a gap that represents the Lower and Middle Jurassic epochs, during which time the Upper Triassic limestone, and possibly an overlying Upper Triassic shale formation, were elevated above the sea and in large part destroyed by erosion before the remainder was again depressed and buried under Upper Jurassic deposits. Whether a period of erosion intervened between the times of deposition of the Upper Jurassic and the Lower Cretaceous beds is not yet evident, but probably if it occurred it was less

[17] Capps, S. R., op. cit., p. 57.

important than that which preceded the Upper Jurassic deposition. On the other hand, a prolonged period of erosion is believed to have preceded the deposition of sediments in Upper Cretaceous time. Thus two, if not three, periods of erosion with resulting unconformities are recorded in the Mesozoic deposits of the Nutzotin Mountains.

It is evident from the statements that have been made previously in describing the sedimentary deposits of different epochs in the Mesozoic that the total thickness of beds is great, although less now than it was when the sediments were laid down. Accurate measurements of thickness are not available, but a rough estimate will serve to give an idea of the great quantity of fragmental material and limestone that accumulated. Capps [18] has suggested a minimum thickness of 3,000 feet for the beds that have been described as Upper Jurassic and Lower Cretaceous. This seems certainly to be a conservative figure. If to this are added the thickness of the Upper Triassic limestone at Nabesna, 2,000 feet, and of the Upper Cretaceous sandstone and conglomerate near Beaver Creek, 1,000 feet, a total of 6,000 feet of sediments is obtained, not including any figure for the thickness of the Upper Triassic arkosic beds on the Snag River. This estimate does not appear to be excessive and probably will be found to be too small.

The Mesozoic beds have been strongly folded and in places are closely compressed and overturned, although open folds are more common. The character of the folding is well shown on a large scale in the mountain faces of the Chisana River Canyon, for the stream flows directly across the strike of the beds in this part of its course and has exposed excellent sections that clearly reveal the structure. In general the strike of the beds is northwesterly, or in conformity with the trend of the mountains in this part of the Alaska Range.

Furthermore, the beds are cut by numerous faults, some of which are of great longitudinal extent and great displacement. One of these faults extends in an east-west direction across the head of Bonanza Creek and brings the Upper Jurassic and Lower Cretaceous area into contact with the Devonian and Permian rocks. This fault possibly is the extension of the fault that passes through the valleys of Notch and Cooper Creeks, separating the Mesozoic and Paleozoic rocks. Another fault of great extent and displacement is thought to be indicated by the straight, northeast front of the Nutzotin Mountains, but its existence is not yet fully established, although a pronounced fault zone separates the Mesozoic from the older rocks on Carden Creek.

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[18] Capps, S. R., op. cit., p. 51.

INTRUSIVES IN THE MESOZOIC ROCKS

Intrusive igneous rocks cut the Mesozoic sedimentary beds in many places. They occur as dikes, sills, and larger bodies of irregular form and variable size and include light-colored granitic and porphyritic varieties belonging chiefly to the andesite-diorite family, together with less abundant dikes and sills of the darker, more basic types. The Upper Triassic limestone at Nabesna was invaded by a small body of quartz diorite, which produced extensive changes in the crystalline character and composition of the host rock. Similar light-colored granitic intrusives were not seen invading the Mesozoic beds stratigraphically above the Nabesna limestone; yet dikes and sills of related rocks cut them and locally are so numerous that they make up a large proportion of the whole rock mass. Their color is medium to dark gray, and in general their composition indicates relation to the acidic and intermediate rather than the basic igneous rocks. Most of them are porphyritic and of rather fine grain, showing few minerals, except the small phenocrysts that can be recognized by the unaided eye. No dikes of this kind were seen in the Upper Cretaceous sandstone, but their apparent absence there needs further confirmation.

The intrusion of these igneous rocks appears to have begun in Jurassic time and to have continued interruptedly into the Tertiary as part of the mountain-building processes that produced the Alaska Range.

The age, as well as the petrographic character and other features of these intrusives, are treated more fully in the section on igneous rocks (pp. 137–153).

AGE OF THE MESOZOIC ROCKS

Previous statements have indicated that the Upper Triassic, Upper Jurassic, Lower Cretaceous, and Upper Cretaceous epochs of the Mesozoic era are represented in the rocks of the Nutzotin Mountains. These assignments have been made on the evidence of fossil remains of plants and animals and are so well established that little change is likely to be made in any of them in the future, other than to restrict further the limit of the ranges, with the possible exception of the youngest of them. It is to be noted that Lower and Middle Triassic rocks are absent, which is in accord with what is known of the lower and middle part of the Triassic elsewhere in Alaska, indicating that Alaska probably was a land mass at that time. The absence of rocks belonging to Lower and Middle Jurassic time is a local condition, for these epochs are represented in other parts of the Territory.

CENOZOIC ROCKS

The known Tertiary sedimentary deposits of the Nutzotin Mountain area include only one small area of unconsolidated gravels, but Tertiary and younger lava flows cover wide areas and have accumulated to a great thickness. Formerly it was believed that certain deposits of sandstone and conglomerate in the vicinity of upper Beaver and Chathenda (Johnson) Creeks were of Tertiary age. As was stated in describing the Mesozoic rocks, the assignment was made on the evidence of a small collection of plant fossils. A reexamination of these fossils in connection with the further field studies makes it appear more probable that these deposits are older than Tertiary and should be assigned to the Upper Cretaceous. That assignment is followed in this report, and in consequence the rocks in question have been treated in the section on Upper Cretaceous deposits.

Unconsolidated deposits of Tertiary age have been recognized only at Gold Hill, which lies between Chathenda (Johnson) and Chavolda (Wilson) Creeks and west of Bonanza Creek. The gravel deposits occupy the summit of this round-topped mountain and are not known to be present at any other locality in the district. They were examined by Capps,[19] who described them as being entirely uncemented and made up of a great variety of rock types, the most numerous of which are lavas and pyroclastic rocks like the rocks of the nearby Devonian and Permian terrains. A much smaller proportion of the material is argillite and graywackè, which may have been derived from the Mesozoic sediments. The pebbles are smooth and well-rounded and generally small. Most of them do not exceed a few inches in diameter, although cobbles and boulders as much as 1 foot in diameter were seen. The deposits carry gold and therefore have received attention from the placer miners. They are rudely stratified, consisting chiefly of alternating fine gravel and sandy layers and reaching a thickness of 200 feet or more. The material taken from a prospecting shaft 150 feet deep was of a reddish or brownish color, and many of the pebbles were so decayed that they fell to pieces on being handled. Pieces of lignitized wood were found in the gravel.

These gravel deposits of Gold Hill are not deformed but evidently are old deposits, as is shown by the condition of the material in them. Those pebbles and cobbles that are susceptible to decay are discolored and partly disintegrated rather than fresh and hard like similar rock fragments in the moraines and recent stream deposits. Furthermore, the position of the gravels on the top of a high hill more than 1,000 feet above Bonanza Creek is such that they could

[19] Capps, S. R., op. cit., p. 55.

not have been deposited there under conditions that have prevailed in recent geologic time. The beds suggest the Nenana gravel, which is present at many places along the north front of the Alaska Range between the Nenana and Gerstle Rivers and is regarded [20] as a late Tertiary deposit; yet a direct correlation is probably not yet justified.

The Cenozoic lava flows are extensively displayed in the area west of the Nabesna River and Glacier and in the mountains south of Beaver Creek. Their general characteristics and petrographic character are considered in the section on igneous rocks in another part of this report (p. 153) but some consideration of the stratigraphic and structural relations of these rocks is necessary in this place. The lava flows and associated pyroclastic beds are not of primary interest for the purposes of this report as they belong chiefly to a bordering area, but they are exposed on the upper part of the Nabesna River and near the glacier and therefore are shown on the map.

These volcanic deposits were called the Wrangell lavas by Mendenhall,[21] who encountered them in the Copper River Valley. They include chiefly andesitic lava flows and interbedded volcanic fragmental material or pyroclastic beds and form the greater part of the Wrangell Mountain group. With the exception of a few thin beds of conglomerate made up of lavas, they do not include known sedimentary members in their lower part and in general appear to have been poured out on the land rather than in water. However, the extrusion of the lavas began in the Tertiary (Eocene)[22] and has continued to the present, so that sedimentary and morainal deposits are included in the upper part in some places.

The earliest of the lavas were poured out on a land surface that had been exposed to the destructive forces of erosion for a long time, yet still retained a marked relief. Fresh-water and land deposits in varying amounts had accumulated in the depressions and were buried by the lavas when they came to the surface. The basal flows therefore rest in many places on underlying thin beds of gravel, sand, or clay, some of which contain plant remains.

Within the area shown on the geologic map the base of the lava flows has been examined in only a few places. The contact of the lavas with the older rocks is well exposed in the mountains northwest of Nabesna. There it appears high above the valley but is seen at successively lower levels as it is followed up Jack Creek

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[20] Capps, S. R., Geology of the Alaska Railroad region: U. S. Geol. Survey Bull. 907, pp. 123–128, 1940. Moffit, F. H., Geology of the Gerstle River district, Alaska: U. S. Geol. Survey Bull. 926–B, pp. 133–134, 1942.

[21] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 54–62, 1905.

[22] Moffit, F. H., Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894, p. 98, 1938.

Valley. The base of the lavas is indicated by light gray or whitish deposits of irregular thickness, which are persistent in this vicinity. Southwest of mile 102 on the highway the light beds reach a thickness of 30 to 40 feet and show a basal bed of unsorted light-gray loose material, which is overlain by banded light and dark sands and clays. Similar light beds appear from place to place for 5 miles or more to the northwest. No fossil plants were seen in these beds.

The lava flows are not folded but are moderately tilted in places and form conspicuous flat-topped mountains south of the Jacksina River. Their thickness in this vicinity is probably not less than 3,000 feet.

The flat-lying lavas that cap the hills south of Beaver Creek are also part of the Wrangell lava. The boundary lines between them and the older underlying rocks have not been accurately traced and are therefore only approximately correct as shown on the map. The lavas occupy an extensive area between Beaver Creek and the White River but are not so thick there as in the Wrangell Mountains.

Although Mount Wrangell and other peaks of the group are built up of lava flows and fragmental rocks that issued from definite vents, it is believed that much of the material of the Wrangell lavas welled up through cracks in the earth's surface that were widely distributed and probably were not places where violent eruptions took place. Furthermore, the statement that eruption of the lavas began in early Tertiary time and has continued to the present does not imply that the process was continuous. Probably periods of volcanic activity were followed by long periods of quiescence. Vast quantities of the lavas and tuffs have been removed by erosion, and although glacial deposits in the Copper River Valley have been cut by recent intrusions and Mount Wrangell occasionally emits ash and steam, there is no evidence of recent activity comparable with that which produced the earlier flows.

The Tertiary (Eocene) age of the earliest lava flows was determined from evidence collected in other districts, particularly in the Chitina River Valley, for fossils were not found in the beds immediately underlying the flows in the Nabesna and Chisana districts. The determination rests on the unconformable relation of the lava flows to the Mesozoic beds and particularly on the evidence of fossil plants in the thin land deposits that the lavas overflowed.

QUATERNARY DEPOSITS

The Quaternary deposits of the area include in addition to the lavas, unconsolidated deposits of sand, gravel, and silt that have undergone more or less sorting by water with or without the intervention of transporting ice; the practically unsorted deposits built up by glacial ice with little assistance from running water; and the angular residual material on hill slopes that is the direct product of weathering. With these may be mentioned a thin veneer of white volcanic ash, which lies below the grass roots, in parts of the area shown on the map, and also a small amount of wind-blown material, such as that of the sand dunes of the Chisana River and the loess of the bottom lands along the larger glacial streams.

The unconsolidated deposits merge into one another and for this reason and because of surface vegetation are difficult to differentiate in many places. This is particularly true of the unsorted rock waste that creeps slowly down the hill slopes and over the margins of older water-laid gravel or moraine, hiding them from view. The different unconsolidated deposits are therefore represented on the map as one formation.

Any gravel deposits that were present before glaciation began were probably swept out of the mountain valleys by the advancing ice, leaving little if any evidence of their existence. The present flood plain and bench gravels are largely the accumulations that were formed while the ice was in retreat and in the interval since that time. Although many of them were laid down in water, they consist in large part of material that was contributed directly to the streams by the glacier ice or was derived from moraines that were torn down and redeposited.

All the larger streams have broad flood plains without vegetation, over which the channels are constantly shifting. As a rule the flood plains are bordered by gravel terraces ranging from a few feet to several hundred feet above the adjacent stream channels and representing older flood plains into which the present channels are incised. In places the terraces are glacial till, elsewhere they are well-sorted water-laid deposits or a combination of both glacial and stream or lake deposits, thus showing that the two kinds of deposits are often intimately related in time and origin.

Flood-plain and terrace-gravel deposits are apt to show a more variable composition than the gravel deposits of the smaller streams, as they commonly are derived from larger areas where the diversity of rock types is greater. They consist in large part of material from a bedrock source within the drainage basin of the stream, yet in many instances they include foreign material contributed by glaciers that originated in neighboring valleys but are no longer in existence.

The gravel deposits of the minor valleys are mostly material from a local source. They repeat on a smaller scale the conditions described for the large valleys insofar as the steeper gradients and restricted space permit, but are relatively shallow and contain a larger proportion of coarse material, especially in areas of very hard rocks.

Glacial deposits are widespread, although not necessarily prominent as topographic features or immediately recognizable on the landscape. They are represented chiefly by till and glacial moraines of the terminal and lateral form. Kettle and kame topography is inconspicuous or absent, except in parts of the lowlands bordering the Nutzotin Mountains near the Snag and Chisana Rivers.

The till forms a thin sheet of loose, unsorted, angular or subangular material, which mantles the bedrock surface or is interbedded with stream deposits. The character of such unconsolidated deposits may be completely masked by the vegetation covering them.

Moraines of the terminal and lateral types are not widely distributed, as they commonly are removed by stream cutting almost as fast as they are formed. However, conspicuous moraines of these types are present in the valley of Beaver Creek. A well-preserved terminal moraine nearly 2 miles long crosses the valley of Beaver Creek just below Carl Creek and is broken only at the place where the creek passes through.

Part of a terminal moraine of the great glacier that occupied the Beaver Valley forms the low hills on the north side of the valley west of Horsfeld Creek. It stands 600 feet higher than the old town of Horsfeld and is composed almost wholly of granitic rock from the granodiorite batholith on the west. This moraine represents one of the later stages in the retreat of the glaciers, for the maximum depth of the ice was more than 1,000 feet, possibly 2,000 feet, at this locality.

Another shorter but equally prominent moraine crosses the valley leading from Horsfeld to Baultoff Creek, near Eureka Creek. This moraine marks the temporary ice front of a part of the Beaver Creek Glacier, which followed the direct, short route through the mountains to the lowland area. A second part of the glacier kept to the south, through the present valley of Beaver Creek, but left no similar deposits in the narrow part of the valley below Horsfeld.

It was expected that extensive terminal moraines might be found in the Nabesna and Chisana Valleys near the places where the rivers leave their canyons and enter the Tanana lowland. Morainal deposits are present but are largely of the ground moraine type and are masked to some extent by the timber cover. If large, continuous terminal moraines were formed they probably were removed by stream cutting. Such terminal moraines are a prominent feature of the Delta River Valley, along the Richardson Highway above Jarvis Creek, where conditions for their building appear to have been comparable to those of the Nabesna and Chisana Rivers when the glaciers were retreating.

Erratic boulders and gravel of foreign origin on ridges and mountain tops bear evidence that the ice reached a great thickness. Such material was not seen in deep deposits at high altitudes but is present over a wide area as a veneer scarcely thick enough to conceal the bedrock on surfaces with low slopes high above the adjacent valleys. These erratics and partly rounded rock fragments are numerous on the flat ridges of the interstream areas between Klein and Fourmile Creeks at altitudes ranging from 5,000 to 6,000 feet. This would indicate a thickness of possibly 2,500 feet for the ice at Horsfeld. It may have been very much greater in the upper Beaver Creek and the Chisana and Nabesna River Valleys. The scanty gravel deposits at high altitudes probably represent material included in the ice, which was left but was not concentrated by running water when the ice was melting.

IGNEOUS ROCKS

By Russell G. Wayland

A large proportion of the rocks of the Chisana and Nabesna districts are of igneous origin. A number of different types have been recognized, but in general three major groups may be distinguished, which differ from each other in mode of occurrence, petrographic character, or geologic age. The petrographic character of some of these rocks will be discussed in the following pages.

The oldest of these groups consists of a series of basic and intermediate lava flows and some pyroclastics and intrusives of Permian age and also some Devonian lavas. The second group of igneous rocks consists of granodioritic rocks, which intrude the Paleozoic and Triassic beds and are considered to be probably of Jurassic age. These intrusive masses range in size from stocks to batholiths, and they have been correlated with the granodioritic intrusives of the Coast Range and Alaska Range.[23] A few small gabbroic intrusives probably belong to this group. The third major group is a thick series of Cenozoic lavas, called the Wrangell lava, most of which lie to the south and west of the map area, in the Wrangell Mountains.

In addition to these three major groups there is a variety of dike rock, most of which is apparently related genetically either to the granodioritic intrusives or to the Wrangell lava, but some of which may be earlier than the granodiorite and related to the Permian lava. The petrographic characteristics of some of these rocks are also described below.

Petrographic studies of igneous rocks are necessary for the interpretation of many geologic problems, among them those that relate to ore deposits. The many technical terms that are needed to describe

[23] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 84–85, 1916.

rocks accurately and without undesirable multiplication of explanatory words are likely to be unfamiliar to those who are not trained in petrographic work. Therefore a considerable part of the descriptions that follow will be of more interest to the geologist than to the reader who is not a specialist.

PALEOZOIC VOLCANIC ROCKS

The stratigraphic relations, age, and distribution of the Permian and Devonian volcanic rocks have already been discussed. The Devonian rocks were found only at Bonanza Creek, near the mouth of Little Eldorado Creek, and are described by Capps.[24] They consist of basic lavas, agglomerates, and tuffs, associated with black shale and graywacke. These rocks were not given further study in the course of this investigation.

The Permian sequence in the Chisana-Nabesna district consists in general of an upper part and a lower part that are dominantly of volcanic origin separated by a middle part that is dominantly of sedimentary origin. The lavas of the lower part of the Permian column are mostly altered basalts and diabases and are essentially similar to those of the upper part. They have not everywhere been recognized and distinguished from the upper Permian lavas. In the field the presence of the lower flows is deduced from their position underlying the Permian sedimentary beds and, as at Bonanza Creek, overlying the Devonian rocks. Where the Devonian rocks, Permian sediments, or Triassic limestones do not crop out as horizon markers, the identity of the Permian lava is much in doubt. The thickness of the upper lavas in the Chisana-Nabesna district cannot be determined with accuracy, because in no single outcrop are both the base and the top exposed. Between Notch and Cross Creeks this upper unit seems to be a thousand feet or more thick. On the map (pl. 8) the Permian rocks are not differentiated, except that in places an attempt has been made to separate flows from sediments and to show some of the more conspicuous limestone outcrops. The petrographic description of the Permian volcanic rocks given below applies equally well, as far as is now known, to the lower and the upper lavas.

The Permian volcanic rocks are mostly flows, but they are interbedded with shales and consist in part of tuffs, breccias, and agglomerates. These latter rock types are collectively called pyroclastics. They are composed of fragmental material which has been ejected during periods of volcanic activity and which usually has been collected and deposited in water with interbedded shales. Some of the interbedded sediments carry marine fossils. The pyroclastics are various

[24] Capps, S. R., op. cit., pp. 31–33.

shades of gray, usually lighter than the associated shales and lavas. They may resemble graywackes and conglomerates in appearance, but they differ from them in that their material is commonly little weathered or water-worn. Many of the fragments are shards of volcanic glass which cooled and solidified so quickly during the eruption that they did not have time to crystallize into minerals.

Many of the Permian flows are so massive that bedding is seen with difficulty, if at all, and they may be mistaken for stocklike intrusive masses where outcrops are not large. In the Chitina Valley some of the Permian lavas show pillow structure,[25] indicating their probable eruption into water. This feature was not noted in the rocks of the Chisana region, but this does not demonstrate that all the flow necessarily extruded on land; rather the association with marine limestones and shales suggests subaqueous solidification of some of the flows.

The Permian lavas are generally amygdaloidal. The amygdules are perhaps their most conspicuous feature, and in the tops of some flows they may constitute as much as 25 percent of the bulk of the rock. The vesicle fillings consist of calcite, chlorite, epidote, quartz, chalcedony, pumpellyite, and prehnite, and thomsonite, pseudomesolite, scolecite, and other zeolites. The pseudomesolite and scolecite were identified chemically by Charles Milton, of the Geological Survey chemical laboratories. Chlorite, calcite, and epidote are the most common amygdules.

At the junction between the two main forks of the Snag River a Permian flow breccia was noted. The rock consists of subrounded fragments of amygdaloidal andesite in a groundmass of dense porphyritic andesite of the same composition and similar appearance. The andesitic matrix shows local flow structures. It is likely that the vesicles in the fragments were filled with chlorite, the dominant amygdaloidal mineral, and a zeolite after the brecciation and the solidification of the matrix. The entire rock is traversed by chlorite veinlets and altered to chlorite, leucoxene, and calcite. Oxide minerals of copper stain the rocks nearby, and a prospect tunnel has been driven in the rock for about 35 feet.

The Permian lavas are generally of a somewhat dull, subdued appearance in contrast with the younger Wrangell lava. Some of the lavas are sufficiently altered to necessitate classification as greenstones even on visiual inspection, but most of them appear fresher in the hand specimen than the thin section shows them actually to be. A few Permian rocks are as fresh in appearance as the Wrangell lava. However, the vesicles of most Permian lavas have been filled, in contrast to those of most of the Wrangell lava.

[25] Moffit, F. H., Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894, p. 38, 1938.

PETROGRAPHY OF THE PERMIAN VOLCANICS

In the hand specimens the Permian lavas show differences, recognizable on close inspection, which depend on the grain size, the texture, the size and number of the phenocrysts, the color of the groundmass, the nature of the recognizable minerals, the character and size of the amygdules, and the amount of chemical alteration that has taken place. As a rule the rocks are not richly porphyritic, and in the hand specimen only the feldspar phenocrysts are usually conspicuous. Most phenocrysts are from 1 to 3 millimeters in size. The groundmass is commonly crystalline but quite fine-grained, appearing aphanitic. A few specimens give evidence of having had a glassy rather than aphanitic groundmass, but the prevalent chloritic alteration has obscured the nature of the groundmass in most specimens. In the few specimens of lavas in which the groundmass is sufficiently coarse-grained for the minerals to be recognized with the naked eye, the texture as shown by the microscope is generally diabasic, and the rock is classed as a coarse-grained diabase or gabbro. The color of most of the Permian lavas is medium gray or dark gray with a greenish hue due to the development of the secondary minerals. Some flows are brownish red in color from the presence of oxidized iron minerals.

Examination with a microscope shows that the Permian lavas were originally mostly basaltic in composition. Some of the flows contain olivine, others do not. The plagioclase phenocrysts are dominantly labradorite, and augite phenocrysts may have been more abundant than hornblende. The common accessory minerals are magnetite, apatite, and titanite. Diabasic textures are common. Andesitic rocks also were probably abundant among the Permian extrusives. However, many rocks are now so altered to chlorite, calcite, epidote, and other such minerals that their original nature is obscure. All the Permian and older rocks seem to have been subjected to a moderate degree of alteration of a regional hydrothermal type. The intensity of this alteration varies with the locality, but its universal presence in at least a small degree is the characteristic feature of these rocks in the Chisana district. There seems to have been no regional dynamic metamorphism, because the chemical alteration of the rocks was not accompanied by the development of schistosity or the type of minerals that commonly form under conditions of stress.

The dense groundmass of the lavas is commonly much altered and becomes a mat of chlorite, sericite, calcite, and leucoxene. Leucoxene is exceptionally abundant in some of the rocks. In specimens from some areas the groundmass is considerably albitized.

The plagioclase crystals are very commonly altered to sericite, chlorite, zoisite, calcite, or kaolin. Many of the plagioclase phenocrysts are somewhat zoned, and the alteration products show preferential replacement. Zoisite particularly favors the calcic cores of zoned feldspars. Specimens from near the junction of the Jacksina and Nabesna Rivers show albitization of the feldspars as a common alteration.

The primary ferromagnesian minerals rarely occur as large, abundant phenocrysts but commonly occur as distinct crystals of small size in a groundmass where much of the material is yet more finely crystalline or glassy. Chlorite is the most abundant alteration mineral of the ferromagnesian minerals, and epidote and calcite are also common. Pyroxenes are extensively altered to uralite in some specimens.

Serpentinous alteration is not as common as normal chloritic alteration. Serpentine veinlets and lining of some amygdules were observed. This serpentine lining of amygdules looks more like a replacement of the walls of the vesicles before they were filled than a filling itself.

In general, epidote alteration is more restricted to veinlets and fractures than is the chloritic alteration, or the calcite alteration when it is present. Some of the epidote veinlets are accompanied by quartz. It is likely that the widespread chloritic alteration preceded some of the epidotization.

Pyrite is found in some of the altered rocks. Kaolin is present as a product of weathering, and some may be related to the hydrothermal alteration. Quartz is introduced as veinlets. Hematite and limonite form readily by weathering of the altered rocks.

The zeolitic minerals are developed chiefly as vein and vesicle fillings and have replaced little or none of the rock. The true zeolites that were found include scolecite, in a specimen of float from the Permian lavas near the Nabesna Glacier; thomsonite, from float at Camp Creek; and pseudomesolite, from float at a tributary gulch near the moraine at Cross Creek. Analcite and heulandite, which were found by Mertie and Moffit[26] in the Nikolai greenstone of the Kotsina-Kuskulana district, were not observed in the Chisana and Nabesna districts but may well be present. A third zeolite described by Moffit and Mertie has optical properties similar to the scolecite found near the Nabesna Glacier. Pumpellyite was found in a specimen from Permian lavas in the low hills in the Nabesna Valley, east of the Nabesna mine. It forms delicate, vitreous green crystals as the innermost coating on the walls of vesicles, the cores of which are

[26] Moffit, F. H. and Mertie, J. B. Jr., The Kotsina-Kuskulana district, Alaska: U. S. Geol. Survey Bull. 745, p. 67, 1923.

filled with coarse epidote and calcite. A mineral resembling prehnite was found in a few specimens of Permian lavas in amounts too small to identify accurately, but prehnite forms a prominent replacement mineral and fracture filling in an altered dacitic dike in the varved upper Mesozoic sediments at the mouth of Cooper Creek.

It seems probable that the hydrothermal alteration of the Permian volcanics and also of the other Paleozoic rocks, including the arkoses and other sediments, is genetically related to the intrusion of the granodioritic masses in Jurassic (?) time. However, the alteration is not confined to the vicinity of the granodioritic masses that are cropping out at the present stage of the erosion cycle. Wide circulation of altering waters was achieved throughout the invaded rocks of the region. These waters may have been meteoric and connate waters, which were heated by the advancing batholithic magmas and augmented by emanations from the magmas.

Some basaltic, gabbroic, and diabasic dikes and sills and a number of dacite and andesite dikes and irregular stocklike bodies are intrusive into the Permian lavas and their associated sediments. Many of these intrusives are found only with the Permian and older rocks and are altered in the same manner as are the Permian lavas, suggesting that they are also Paleozoic in age and related genetically to the lavas. Where the intrusives cut through sediments they are especially apt to be calcitized. But some intrusive rocks, especially the dacites, are comparatively fresh, and as dacites and andesites are common among the minor intrusive rocks accompanying the granodiorite it is likely that some of these rocks are Jurassic (?) age. A few spessartite-lamprohyre dikes similar to some known to accompany the granodiorite are also associated with these fresher intrusives into the Permian.

GRANITOID INTRUSIVE ROCKS

Granodioritic and gabbroic rocks are exposed at a number of localities throughout the region. The largest body is the granodiorite batholith into which Klein, Carl, Horsfeld, Gravel, Baultoff, and Crescent Creeks have carved their valleys and which has an outcrop area of 120 square miles. Other granodioritic masses of considerable size are exposed along Notch and Cooper Creeks, at Bond Creek, and at Monte Cristo Creek. Smaller bodies crop out at White Mountain, between Notch and Cross Creeks, between Chathenda (Johnson) and Chavolda (Wilson) Creeks, along Gravel Creek, and along the north front of the Nutzotin Mountains, near Carden Creek. A notable occurrence of gabbro is at the intersection of Beaver and Ptarmigan Creeks, and a gabbroic rock is prominent in the isolated mountains north of Carden Lake.

KLEIN CREEK DISTRICT

The large batholith in the eastern part of the district extends from Carl Creek to the international boundary, a distance of 21 miles, and has a maximum width of 10 miles from north to south. The greatest width is at the western end. According to Cairnes,[27] the eastern end of the batholith is about 2 miles beyond the Alaskan boundary, in Yukon Territory. From Horsfeld eastward the exposed width is less than 4 miles. In the Gravel Creek and Horsfeld Creek areas there is a large pendant of varved sediments of Paleozoic or possibly Mesozoic age.

The granodiorite of the batholith is a granular rock, consisting, as far as the eye can determine, of plagioclase feldspar, biotite, and hornblende. It varies from place to place, both in mineral composition and in texture. Quartz and orthoclase are recognizable by the unaided eye in some hand specimens, as at Lamb's Pass. Biotite or hornblende may occur exclusive of each other, but both are commonly present. As seen under the microscope, the granodiorite displays a hypidiomorphic granular texture. The plagioclase feldspar is commonly andesine. The ferromagnesian minerals are biotite, hornblende, and some augite. Orthoclase feldspar is usually present in subordinate amounts but may total as much as 15 percent of the rock, and quartz may constitute as much as 25 percent. Magnetite, titanite, and apatite are the accessory minerals. Secondary alteration products, such as chlorite, sericite, calcite, epidote and zoisite, are prevalent.

Typical of the more acidic facies of the batholith is an area of pinkish granite half a mile south of the southern Carl Glacier. It is a granular rock of medium grain, consisting macroscopically of quartz and gray plagioclase crystals set in pink orthoclase, and with very few dark minerals. Under the microscope the texture is seen to be allotriomorphic granular. Orthoclase, quartz, and oligoclase, named in order of abundance, make up 95 percent of the rock. The remainder is chiefly biotite and chlorite. Magnetite, zircon, apatite, and titanite are the accessory minerals. Chlorite, epidote, kaolin, and sericite are the secondary minerals.

The parts of the batholith exposed at the head of Gravel Creek and of Baultoff Creek, north of the pendant, are in general more basic than most of the rest of the batholith. At the head of Gravel Creek the rock is darker in color than ordinary granodiorite, chiefly because the plagioclase feldspars are darker gray than in the granodiorites but also because mafic minerals make up 30 percent of the rock. Under the microscope the dominant mineral is seen to be andesine feldspar. Orthoclase feldspar is present, but quartz occurs in only minor

[27] Cairnes, D. D., Upper White River district, Yukon: Canada Geol. Survey, Summary Rept. for 1913, pp. 12–28, 1914.

amounts. The ferromagnesian minerals are biotite, hornblende, and augite, named in order of abundance. Magnetite and apatite are the most abundant accessory minerals. Because of the appreciable orthoclase and the small amount of quartz the rock is classed as monzodiorite.

A mile northeast of the monzodiorite, on the eastern fork of Baultoff Creek, the rock of the batholith is even more basic. It is a dark-gray, fine-grained, granular rock, a third of which is composed of ferromagnesian minerals. Under the microscope the texture is found to be allotriomorphic granular. The dominant plagioclase is distinctly zoned, with labradorite cores and abrupt transition to andesine rims. There is no quartz or orthoclase. Hornblende and some augite and magnetite are the dominant ferromagnesian minerals. The hornblende is interstitial to the plagioclase and may be a deuteric alteration of augite. Chlorite and a little epidote and leucoxene are the secondary minerals, and apatite and titanite are the accessory minerals. The rock is classed as diorite.

At Crescent Creek, 5 miles northwest of the diorite of Baultoff Creek, the rock of the batholith is again granodiorite, typical of the average rock of the mass. The ferromagnesian minerals are hornblende and biotite. Quartz is inconspicuous but pinkish orthoclase is noticeable in the hand specimen.

Flow structures are commonly lacking or inconspicuous in the batholith at Klein Creek, so far as observed. Time did not permit study of these features or of the primary fractures, so nothing is known of the internal structure of the batholith. The existence of the pendant at Gravel and Horsfeld Creeks, the mineralization at Baultoff Creek, the more basic rocks in the tongue of the batholith north of the pendant, and the granodioritic stocks along Gravel Creek all indicate that the present erosion surface at the northeast portion of the batholith area is cut near the roof of the batholith. Elsewhere, as in the Carl Creek region, the more abrupt and regular contact of the batholith with the invaded rock and the comparative lack of marked contact effects and of pendants or of isolated blocks of country rock in the granodiorite suggest exposure of deeper parts of the batholith.

Adjacent to the batholith and west of Carl Creek, cropping out for more than a mile, is a dark-green basalt, which appears to be a thick sill-like intrusive in the Permian rocks. It may be genetically related to the granodiorite, or it may be a much earlier intrusive in the Permian rocks. It consists of small labradorite phenocrysts in a groundmass of hornblende, magnetite, and feldspar. It is much chloritized and has considerable epidote and pyrite, an alteration very much like that undergone by most of the Permian rocks.

This batholith, which has its most prominent expression in the mountains about the heads of Carl, Klein, Gravel, Horsfeld, Baultoff, and Crescent Creeks, is apparently younger than Permian and older than Upper Jurassic. It cuts across formations that include limestones with Permian fossils. Nowhere was the batholith observed in direct contact with Triassic rocks, but the Upper Triassic beds of the Crescent Creek and Snag regions are involved in the same folds and trends around the northern part of the batholith as are the Permian rocks. On Gravel Creek are some nearly horizontal shales and conglomerates which lie between exposed granitic stocks and are apparently unaffected by granitic intrusion. The conglomerates are well consolidated and contain granodioritic boulders. Fossils found in these beds by Moffit have been tentatively classed as Upper Jurassic by J. B. Reeside. Presumably the intrusion took place later than Upper Triassic and before Upper Jurassic time.

CHISANA AREA

The intrusive masses between Chathenda (Johnson) and Chavolda (Wilson) Creeks, east of the town of Chisana, were not re-examined by the writers, as they were studied by Capps [28] in 1914. They are granodiorite very similar to that of the batholith of the Klein Creek region. The writers noted that the part outcropping along the trail between Chisana and Bonanza was the body of oligoclase andesite mentioned by Capps. It consisted of plagioclase and biotite crystals in a dense gray matrix.

The granodiorite is presumbly older than the flat-lying Upper Cretaceous sediments of Chathenda (Johnson) Creek. It is intrusive into Paleozoic rocks, and according to Capps is in fault contact on the north with the varved Mesozoic argillites.

NOTCH AND COOPER CREEKS

The granodioritic batholith that is exposed in the mountains southwest of Notch and Cooper Creeks may be the east end of the intrusive mass exposed at Bond Creek and Monte Cristo Creek, near the Nabesna Glacier. If so, the size of the batholith is comparable to that of the one at Klein Creek. However, the center of the area was not visited, chiefly because of lack of time.

At Notch Creek the east end of the batholith is a long, narrow tongue, which cuts into basalt flows and a crystalline limestone that is presumably Permian in age. At the extreme eastern end are some andesitic and granitic dikes and a few lamprophyric rocks. A very

[28] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 84–86, 1916.

small stocklike dioritic mass crops out about a mile southeast of the tip of the principal intrusive. At Cooper Pass the width of the batholith increases considerably.

The most abundant facies of the batholith at Notch Creek and Cooper Pass is a typical granodiorite, very much like the common facies of the batholith at Klein Creek. In the hand specimen the ferromagnesian minerals appear to be chloritized biotite and hornblende, and they form about a quarter of the bulk. Some quartz is noticeable, but most of the rest of the rock appears to be a light-gray plagioclase feldspar. Under the microscope the texture is seen to be hypidiomorphic granular, medium grained. Andesine feldspar, quartz, and orthoclase feldspar are the light colored-minerals, named in order of abundance. The ferromagnesian minerals are to a large extent chloritized, but it is probable that biotite would exceed hornblende in quantity in a fresh specimen. Other alteration minerals are sericite and zoisite in the feldspars and calcite and epidote in the mafic areas. The principal accessory minerals are magnetite, titanite, and apatite.

At the east end of the batholith at Notch Creek some of the rock is a more basic phase of the intrusive. In the hand specimen it appears as a medium-grained diorite two-thirds of which is gray feldspar and one-third ferromagnesian minerals. The microscope shows it to have a hypidiomorphic texture and to consist dominantly of andesine and hornblende. There is, however, about 10 percent of quartz and 5 percent of orthoclase and some biotite. Augite is present in the cores of some of the hornblende crystals. Secondary minerals, sericite, epidote, chlorite, and pyrite, are not abundant. The accessory minerals are magnetite, apatite, zircon, and titanite. This rock is classed as a quartz diorite.

Small dikes of fine-grained granite cut the granodiorite at Notch Creek. In the hand specimen they are pinkish white, with few dark minerals. In thin section they are seen to be allotriomorphic equigranular in texture, with crystals about a millimeter in diameter. Orthoclase feldspar comprises 50 percent of the rock and quartz 35 percent. The remainder consists mostly of oligoclase feldspar, with a little biotite, chlorite, titanite, apatite, and magnetite.

An abundant intrusive rock that occurs with the granodiorite is a light-gray dense dacite porphyry. The grains of the groundmass are about 30 microns in size and constitute 60 percent of the rock, and consist of quartz and oligoclase and some orthoclase, magnetite, and apatite. The phenocrysts are 2 millimeters long or less and consist of oligoclase, quartz, and hornblende, named in order of abundance. The oligoclase is much zoned, ranging from An_{40} cores to An_{15} rims, and is euhedral but somewhat corroded.

BOND AND MONTE CRISTO CREEKS

Except for a few of the outcrops along the west bank of the Nabesna River, the batholithic rocks on Bond and Monte Cristo Creeks near the Nabesna Glacier were not visited during the course of the present investigation. They had been studied by Schrader in 1902 and by Moffit and Knopf [29] in 1908, and the writer reviewed the notes and thin sections collected by those parties.

The dominant rock of the batholith exposed at Bond Creek and at Monte Cristo Creek is granodiorite similar to that of the batholiths at Cooper Creek and at Klein Creek. The same rock also crops out in a small area on the west bank of the Nabesna River, opposite Bond Creek. Thin sections of the granodiorites show the light-colored minerals to be chiefly andesine with orthoclase and quartz, and the dark minerals to be hornblende, biotite, and magnetite. Some of the andesine is zoned with labradorite cores. Augite forms cores in some of the hornblende crystals. Accessory minerals are apatite and titanite. Chlorite, epidote, kaolin, sericite, leucoxene, and pyrite are the common alteration minerals, appearing especially at Monte Cristo Creek. These rocks were called quartz diorites rather than granodiorites by Schrader and by Moffit and Knopf, but nearly all specimens contain more than enough orthoclase to cause them to be classified as granodiorites according to present-day usage.

Quartz diorite facies of the batholith are common, although relatively much less abundant than the granodiorite. Specimens from the west bank of the Nabesna River north of Monte Cristo Creek and from Orange Hill differ from the granodiorite in having less biotite and considerably more hornblende and in being more or less devoid of orthoclase. The quartz diorite of Orange Hill is mineralized with disseminated chalcopyrite and pyrite.

A prominent intrusive rock associated with the granodiorite in the Nabesna region is a dacite porphyry. This rock carries numerous euhedral zoned phenocrysts of andesine with labradorite cores. Anhedral quartz phenocrysts are common, and hornblende phenocrysts or biotite also occur. The groundmass is aphanitic or cryptocrystalline and consists of sodic plagioclase, orthoclase, quartz, hornblende, and magnetite. The same secondary minerals as those that occur in the granodiorite have usually been developed, and some specimens are much altered.

Andesites also are common intrusive rocks associated with the granodiorite. Generally speaking, the andesites are more sparsely porphyritic than the dacites. They contain no noticeable quartz or

[29] Moffit, F. H. and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, pp. 44–45, 1910.

biotite. Along the west bank of the Nabesna River, opposite Bond Creek, a gray andesitic rock with white feldspar phenocrysts forms the core of a prominent hill. It is a large sill-like body, which dips gently southward. Microscopic examination shows it to be a glomeroporphyry with clusters of andesine and hornblende phenocrysts and a groundmass composed of oligoclase with some orthoclase, magnetite, and apatite. No quartz was observed. Calcite and sericite are secondary minerals.

A small intrusive body of medium coarse grain and granitoid texture crops out along the bank of Jacksina Creek, near its mouth. It is a dark-gray rock, consisting chiefly of andesine and hornblende, with some augite and little or no orthoclase and quartz, and it is classed as a diorite.

OTHER OCCURRENCES OF GRANITOID ROCKS

At White Mountain a small isolated stock of quartz diorite, with associated dioritic and andesitic dikes, intrudes the Triassic limestones, causing considerable contact metamorphism and the deposition of the gold pyrite ores of the Nabesna mine. This rock is described petrographically on page 148.

A small stock of porphyritic gabbro intrusive into Paleozoic rocks crops out along Beaver Creek, near Ptarmigan Creek. It consists chiefly of augite and labradorite, with some hornblende and magnetite and a little deuteric biotite. Secondary minerals, chiefly chlorite and sericite, are developed. This rock is the host to a small gold deposit, in which the gold is associated with arsenopyrite, pyrrhotite, pyrite, chalcopyrite, quartz, and calcite.

Along the north front of the Nutzotin Mountains, between the Snag River and Beaver Creek, is a belt of older crystalline rocks into which are intruded some small granodioritic bodies with which is associated an unusual amount of metamorphism of a type resembling granitization. The small intrusives themselves show gneissic structure for the most part. The microscope shows a typical specimen to consist of oligoclase-albite, quartz, orthoclase, and some biotite and hornblende. The rock is very much altered, yielding sericite, zoisite, chlorite, and some hematite and limonite as alteration minerals. Accessory minerals are zircon, apatite, ilmenite, and titanite. The field relations and genesis of these rocks are discussed further under the section on contact alteration.

The backbone of the Carden Hills north and west of Carden Lake is made up of an unusual gabbroic rock. In the hand specimen it looks like a coarse-grained pyroxenite. The microscope shows that two-thirds of it is a coarse augite and one-third is labradorite and bytownite feldspar. The augite appears to be a variety low in ferrous iron. It has an excellent prismatic cleavage, a moderate optic angle, a pale bronze-green color and no noticeable pleochroism in thin section. Scattered through the augite in random fashion are small crystals of tremolite. The bytownite is also saussuritized by what appear to be tremolite needles. A little pyrite appears in one specimen. No olivine was observed, and there is a notable dearth of magnetite and other opaque oxide minerals.

Lamprophyric rocks were noted at a number of localities. The most abundant type is spessartite lamprophyre. It commonly shows conspicuous large, black, euhedral phenocrysts of hornblende in a dense gray matrix. Such rocks were seen in talus at the east end of the batholith, at Notch Creek; in the float of Bonanza Creek; and in talus north of the batholith, near the glaciers heading Baultoff and Crescent Creeks. Rocks of similar mineralogy but having smaller hornblende crystals were noted in place as dikes cutting the upper Mesozoic varved slates and graywackes north of Crescent Creek and as a series of dikes cutting dacite porphyry in the gulch south of the terminal moraine at Cross Creek. The groundmass is composed of hornblende and of plagioclase-feldspar ranging from sodic to intermediate compositions. The phenocrysts are dominantly basaltic hornblende, with less abundant augite. Secondary minerals are calcite, leucoxene, chlorite, epidote, zoisite, and sericite. The common accessory minerals are magnetite, ilmenite, titanite, and apatite.

A somewhat unusual lamprophyre was observed in the float of the second gulch northeast of the terminal moraine of Cross Creek. It is a coarse-grained rock containing dark-green bladed crystals in random orientation. The blades are conspicuous because of the development of one excellent lustrous cleavage face parallel to the elongation. Between the green crystals are pale-greenish or white feldspar crystals, which are also coarse grained. Under the microscope the green mineral is seen to be pigeonite, a pleochroic variety of pyroxene with a small optic angle. The feldspar is albite. Magnetite and titanite are present in small amounts, and there is considerable alteration of the primary minerals to uralite, chlorite, leucoxene, and epidote.

CONTACT ALTERATION

The larger bodies of granodioritic rocks have produced variable amounts of alteration of the sedimentary and volcanic rocks along their borders. At some localities these contact effects are noticeable even at some distance because of the yellow-reddish color resulting from the weathering of the altered rocks. The rocks at the southern tributary to Baultoff Creek, 3 miles southeast of the pass to the Snag River, afford a good example of this alteration. On closer inspection this color is found to be due to deposition of iron oxides and hydroxides along the cleavage, joint, and bedding planes of the rocks or to considerable alteration of the rocks. Copper carbonates and hydrous ferric sulfates form coatings on some of the outcrops.

Contact metamorphism has been observed in the vicinity of several of the granodioritic bodies. The most conspicuous changes are in the Permian and Upper Triassic limestones where they have been coarsely crystallized and especially where tactitic minerals, such as garnet, diopside, vesuvianite and magnetite, have formed. Less conspicuous but readily observable in the region north of the Klein Creek batholith is the partial silicification of some of the Paleozoic (?) varved argillites. On upper Horsfeld Creek a biotitic hornfels has formed from arkosic sedimentary beds at the granodiorite contact, and in the crystalline belt of rocks along the north front of the Nutzotin Mountains coarse biotite-quartz-andesine-garnet gneiss has been formed in the vicinity of small granodioritic bodies.

Tactite bodies in Permian or Triassic limestone near granodioritic or quartz dioritic bodies are known at White Mountain, Orange Hill, and Cooper Pass and are likely to be found elsewhere under similar geologic conditions. The bodies at White Mountain are in the vicinity of the Nabesna mine and are apparently genetically related not only to the quartz dioritic intrusives of that mountain but also to the gold-pyrite mineralization. They are described in greater detail on pages 180–183 and will be but briefly described here. In general, the small quartz dioritic stock and smaller bodies of quartz diorite are intrusive into Triassic limestone at White Mountain and have crystallized the limestone by their heat, pressure, and aqueous emanations. Locally there has been introduction of solutions bearing iron and silica and other such substances, which have reacted with the limestone to form andradite garnet, vesuvianite, diopside-hedenbergite, magnetite, epidote, chlorite, wollastonite, specularite, and other minerals. In late stages of the crystallization of the magma the solutions that escaped deposited pyrite, some pyrrhotite, chalcopyrite, sphalerite, galena, and gold.

Limestone beds 1,200 feet thick are exposed east of the quartz diorite of Orange Hill. According to Pilgrim,[30] they dip gently to the northeast and are generally massive, but in a few places they show a more thinly bedded structure. In the vicinity of the quartz diorite and associated dikes the limestone is coarsely crystalline, silicified, and locally altered to tactite. A specimen collected by Moffit from the Shamrock claim in 1908 consists of crystalline limestone replaced by fibrous wollastonite and garnet. Other minerals

[30] Pilgrim, E. R., Alaska Nabesna Orange Hill copper claims: Report on cooperation between the Territory of Alaska and the United States in making mining investigations and in inspection of mines for the biennium ending March 31, 1931, pp. 70–74, 1931.

are magnetite, pyrrhotite, chalcopyrite, bornite, quartz, copper carbonates, and a little molybdenite. Some of the "green garnet" reported by Pilgrim [31] may be vesuvianite like that at White Mountain.

Local tactitic development of diopside, andradite, magnetite, and specularite occurs in Cooper Pass in a massive light-gray crystalline limestone adjacent to the batholith. Near the Notch Creek Glacier there is some pyrrhotite-pyrite mineralization, and farther to the southeast, along the south fork of Notch Creek, the limestone is again coarsely crystalline, although no tactite was noted.

The batholith at Klein Creek seems not to have developed any extensive tactitic zones in limestone nor coarse crystallization of limestone, probably because it has no observed direct contacts with limestone. The granodiorite has produced a hornfels of what was probably originally an arkosic sediment near the east fork of Horsfeld Creek. The hornfels crops out over an area of a few acres on a sharp ridge. In the hand specimen the rock is black and of medium to fine grain, with lustrous black mica crystals. The microscope shows the rock to consist of quartz, biotite, and andesine-oligoclase, named in order of abundance. Also present are apatite, magnetite, pyrite, and limonite. The texture is porphyroblastic nonfoliate. The dominant agency in the formation of the hornfels seems to have been hot aqueous emanations.

The rocks of the pendant of Paleozoic (?) beds in the upper Horsfeld Creek-Gravel Creek area are to a large measure varved argillites which have been well indurated and at least locally silicified. Their alteration is perhaps in part direct contact metamorphism and in part a variation of the regional chemical alteration that has chloritized the Paleozoic basalts, andesites, and graywackes. Similar rocks appear in the headwater region of the south fork of the Snag River.

The gneisses produced locally in the phyllites along the north front of the Nutzotin Mountains are directly connected with small granodioritic bodies. The amount of crystallization is much out of proportion to the size of the granodiorite bodies in comparison with the metamorphism of noncalcareous rocks around the larger granodioritic masses of the Chisana district. The gneiss commonly grades directly into the granodiorite, which is in itself gneissic and has foliation in general parallel to the northwest regional trend of schistosity in the phyllites. In some gneissic areas there is no exposure of granodioritic rock. The gneiss commonly grades to phyllite through a zone of biotite or hornblende schist. Perpendicular to the regional strike this gradation is more rapid than it is along the strike of the formations. Boundaries are hard to determine, and

[31] Pilgrim, E. R., op. cit., p. 71.

as the belt of such metamorphism is small and the outcrops rather poor no attempt has been made to show on the map anything but a few of the larger of the small granodiorites. At Carden Creek a small prospect is reported to show gold ore near one of these intrusives.

The writer suggests that these small granodioritic bodies with much gneissic development are the very uppermost parts of larger bodies of granodiorite or are direct offshoots from an unexposed magma, presumably granodioritic, which produced a local metamorphism comparable to granitization. It is recognized that the amount of contact metamorphism near the uppermost projection of a large acidic intrusive magma is commonly much greater than near parts of the intrusive exposed by deeper erosion. This seems to be due to the tendency of the magmatic emanations to rise along fractures or to permeate through the rocks above the magma, seeking the direction of lowest pressure. When the magma is still far below the crust and surrounded by country rock that is itself under high pressure and temperature, these emanations are thought to be capable of reacting with the country rock to produce a rock approaching the composition of the advancing magma. If this replacement process is complete and the product resembles an igneous rock the country rock is "granitized." In the granitization at Carden Creek the minerals produced are oligoclase-andesine, biotite, quartz, and hornblende in proportions not unlike those in true granodiorites. In addition there is some almandite garnet. The gneissic structure, the gradational contact with schist, the lack of uniformity of distribution of the darker minerals, and the presence of almandite all serve to distinguish the granitized country rock from what might here be considered normal gneissic granodiorite.

SUMMARY OF AGE RELATIONS

The large batholith of the Klein Creek district is the most closely dated of all the granodioritic bodies. It invades rocks of undoubted Permian age, and rocks of Upper Triassic age are involved in the same structures and chemical alteration as the Permian rocks at Reynolds Creek, the next southern tributary of the East Fork below Crescent Creek. But at Gravel Creek there is an undisturbed conglomerate containing granodiorite boulders and fossils that are regarded by J. B. Reeside as probably of Upper Jurassic age. It would seem, therefore, that this granodioritic mass was intruded between Upper Triassic and Upper Jurassic times.

The small dioritic stock at Nabesna invades the Upper Triassic Nabesna limestone. The batholith at Cooper Pass has metamorphosed a limestone that is probably Permian, although it may be

Triassic. Most of the other granodioritic bodies invade the Paleozoic rocks.

The great series of upper Mesozoic varved argillites and graywackes that makes up the heart of the Nutzotin Mountains northeast of the Snag River is notably free from granodioritic intrusives. The age of these rocks is thought possibly to be Upper Jurassic or Lower Cretaceous, but they are poorly fossiliferous and future discoveries of fossils in them should be awaited. These rocks are cut by a number of andesitic and dacitic dikes, especially near their southern margin, in the region east of the Chisana River. Dikes of augite spessartite lamprophyre were found north of Crescent Creek in the varved argillites and graywackes. Hence it seems that many such rocks are later than the granodioritic masses with which many other similar rocks appear to be associated, and the suggestion is made that such igneous activity in this region may have continued on a small scale throughout the Cretaceous or may have been associated with the Wrangell extrusives.

WRANGELL LAVA

The distribution and stratigraphic relations of the Wrangell lava have been set forth earlier in this bulletin (pp. 132–134). The lavas appear only in the southern and western parts of the area included on the map of the Nutzotin Mountain area, but were evidently more extensive in this region before the recent erosion. At Mount Wrangell and perhaps elsewhere lava eruptions continued until recent times, but in the region under discussion no lavas younger than the latest glacial stage were observed. For the most part, the lavas form the capping of some of the higher hills. They lie almost horizontally upon an irregular erosion surface of early Tertiary age. The recent erosion along the courses of the Jacksina River and its tributaries and along the creeks south of Beaver Creek has cut into the Wrangell lava and shown it to consist of a succession of flows and a few tuffs. Everywhere the bedding is pronounced, and some of the beds display columnar structure.

The Wrangell lava is commonly quite fresh, both in outward appearance and under the microscope. For the most part the rocks are dark and gray colored, although a few are brick red, lavender, or tan color. Most of the lavas are porphyritic, but few show phenocrysts in excess of the groundmass. Many of the flows are highly vesicular or scoriaceous, though in only a few are the vesicles filled with amygdules. Obsidian is observed uncommonly.

The Wrangell lava of the western slopes of the Wrangell Mountains has been described in some detail by Mendenhall,[32] and that of

[32] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 54–62, 1905.

the Chisana region was described by Moffit and Knopf [33] and by Capps.[34] Because of the reconnaissance nature of the current field work in this region, the Wrangell lava there was not extensively restudied. Schrader in 1902 collected about 48 different specimens from the Wrangell lava along the Jacksina River. The writer studied Schrader's thin sections and notes, along with some new specimens.

The most abundant and widespread flows are medium to dark gray in color. Nearly all are sparsely porphyritic. The groundmass is commonly either glassy with crystallites or is cryptocrystalline to fine-grained crystalline. The refractive indices of all glassy groundmasses noted are less than the refractive index of balsam, indicating that the compositions are probably intermediate to acidic. No rocks have a groundmass sufficiently crystalline for the individual grains to be distinguished without the aid of a microscope. The feldspar phenocrysts are commonly labradorite, less commonly andesine, and they range in size from 0.5 to 3 millimeters. Most plagioclase crystals are euhedral and somewhat zoned and are lighter in color than the groundmass. Ferromagnesian minerals occur less abundantly as phenocrysts than do feldspars and the crystals are generally smaller. In the order of frequency of appearance they are hypersthene, hornblende, augite, and olivine. Biotite was not noted among the phenocrysts of any specimens. Magnetite is present as disseminated small crystals in nearly all the specimens.

A specimen collected from Euchre Mountain is a specific example of a typical Wrangell lava. It is a vitrophyre and consists of a few phenocrysts of labradorite and hypersthene, with some smaller crystals of labradorite, hypersthene, augite, olivine, magnetite, and some crystallites set in a dark glassy matrix of intermediate composition. Some of the hypersthene crystals are rimmed with augite. No quartz is present. This particular rock occurs in flows overlying a 300-foot bed of Upper Cretaceous arkose near the north end of the Chisana Glacier.

Most of the rocks of the Wrangell lava that have been described might be classed as basalts from the petrographic evidence based on determination of the phenocrysts. However, four available analyses of typical specimens are given in the table, and the petrographic descriptions that follow show that the first three analyses are of rocks not greatly unlike the typical Wrangell lava described above. That the rocks are chemically andesites suggests that most of the Wrangell lavas are also andesites rather than basalts. It is therefore

[33] Moffit, F. H. and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, pp. 32–36, 1910.

[34] Capps, S. R., The Chisana-White River District, Alaska: U. S. Geol. Survey Bull. 630, pp. 58–61, 1916.

indicated that the glassy and cryptocrystalline groundmass of the average rock contains soda, silica, and some potash in proportions greater than in the crystalline minerals of the rock.

Analyses of Wrangell lava

	A	B	C	D
SiO_2	67.04	61.31	62.67	70.94
Al_2O_3	16.71	16.70	16.62	13.96
Fe_2O_3	1.46	1.30	3.25	1.74
FeO	2.08	4.08	1.17	1.69
MgO	1.09	3.44	3.08	.12
CaO	3.26	6.10	5.56	1.13
Na_2O	5.07	4.05	4.24	5.64
K_2O	1.84	1.58	1.67	4.03
H_2O-	.51	.36	1.01	.45
H_2O+	.08	.22	.23	.09
TiO_2	.51	.73	.48	.30
ZrO_2	.05	.01	.01	.05
P_2O_5	.27	.18	.15	.10
MnO	.16	.14	.11	.15
NiO	0	.02	.01	0
BaO	.03	.05	.06	.06
SrO	Trace	.02	.03	Trace
Li_2O	0	Trace	Trace	0
Total	100.16	100.29	100.35	100.45

CO_2 and SO_3 absent.
A. Schrader 1222, hypersthene andesite. G. W. Steiger, analyst.
B. Mendenhall, hypersthene andesite. W. F. Hillebrand, analyst.
C. Mendenhall, weathered hypersthene andesite. W. F. Hillebrand, analyst.
D. Schrader 1146, quartz latite. G. W. Steiger, analyst.

Norms of Wrangell lava

	A	B	C	D
Quartz	21.61	12.78	16.56	20.58
Zircon	.07			.07
Corundum	.99			
Orthoclase	10.90	9.45	10.01	23.85
Albite	42.86	34.06	35.63	47.68
Anorthite	14.65	22.80	21.41	.83
Diopside		5.66	4.47	3.37
Hypersthene	4.78	11.39	5.60	
Wollastonite				.17
Magnetite	2.11	1.86	2.78	2.53
Ilmenite	.97	1.37	.91	.56
Apatite	.59	.34	.31	.22
Mematite			1.38	
(Water)	(.59)	(.58)	(1.24)	(.54)
Total	100.12	100.29	100.30	100.40
Symbol	I″. 4. 2″. 4	II. 4″. 3. 4	(I)II. 4. 3. 4	I″. 4. 1. 3″

Analysis A of a specimen of hypersthene andesite, which Schrader collected from the Wrangell lava about 3 miles southwest of the Nabesna mine, has been published by Moffit and Knopf.[85] In his field notes Schrader describes the specimen as fresh, ashen-gray massive aphanite, and he evidently considered it typical of abundant rocks of the series. In thin section the rock is seen to consist of a cryptocrystalline groundmass, which makes up half of the volume, and crystals ranging in size from 0.05 to 2 millimeters. The index of the groundmass is lower than that of balsam, indicating that it is intermediate or siliceous in composition. There are many white crystallites, which are elongate like sodic plagioclase and are arranged in parallel flow structure. Magnetite and some ferromagnesian crystallites, are widespread. The dominant mineral of the phenocrysts is plagioclase, which occurs as fresh, tabular, euhedral crystals with Carlsbad twins, broad albite twinning bands, noticeable dispersion, and with inclusions and zoning. The zoned crystals commonly have labradorite cores and grade rather uniformly outward toward andesine until at the outermost rim, there is a reversal to labradorite. According to Bowen's reaction theory,[86] this indicates that the plagioclase crystals may have settled in the liquid in which they were crystallizing, thus falling into liquid at a higher temperature, in which, because of the higher temperature, crystals of a more calcic plagioclase were in equilibrium.

Within the larger plagioclase phenocrysts are irregular inclusions of brown glass of low refractive index, which are difficult to explain, because they are presumably older than the crystal that contains them yet they have not crystallized. In some crystals there has been formed a reaction rim in the plagioclase near the included glass which consists of a clear zone of calcic plagioclase. Some of the inclusions have a graphical arrangement in the plagioclase.

Hypersthene is the second most abundant crystalline mineral of the rock. It occurs in crystals about 0.05 to 0.5 millimeter in size and displays its usual optical properties. The crystals are elongate and bluntly terminated. A few scraggly crystals of augite, a considerable number of disseminated small magnetite crystals, and a few apatite needles make up the rest of the recognizable minerals. No quartz or mica was noted. G. W. Steiger's analysis of this rock is repeated in the table as analysis A, and the norm has been recalculated by the writer, the molecular proportion being carried to an extra decimal, as suggested by Mertie.[87] From the norm and analysis the rock is

[85] Moffit, F. H., and Knopf, Adolph, op. cit., p. 34.

[86] Bowen, N. L., The evolution of the igneous rocks, pp. 274–276, Princeton Univ. Press, 1928.

[87] Mertie, J. B. Jr., The Nushagak district, Alaska: U. S. Geol. Survey Bull. 903, p. 80, 1938.

classed as a lassenose under the system of Cross, Iddings, Pirsson, and Washington.[38] Most aphanites that are classed as lassenose from their norms have been described petrographically as dacites, but there is poor agreement, and several have been called andesites and rhyolites. This rock should probably be classed as a porphyritic hypersthene andesite in spite of the labradorite phenocrysts, because the chemical composition shows that the groundmass is high enough in soda and silica for the rock to be a dacite. If the quartz were showing, the rock would indeed be called a dacite. The compositional range of the phenocrysts of this rock differs from that of the groundmass more than is usual in lavas.

Mendenhall[39] describes and gives analyses for two similar but less siliceous rocks from 40 miles southwest of Nabesna, one from the southern slope of Mount Wrangell and the other from the southwest slope of Mount Drum. The first is a vesicular hypersthene andesite vitrophyr, the second a gray porphyritic hornblende andesite with a little biotite and hypersthene. The second rock is somewhat weathered. In both rocks the phenocrysts are mostly labradorite. From their norms they are both classed as tonalose. The analyses and the norms given by Mendenhall are reprinted here as B and C in the table.

The analysis of another rock collected by Schrader was published by Moffit and Knopf.[40] Although it comes from Mount Sanford, at the foot of Drop Glacier, 30 miles due west of Nabesna, and is therefore not from within the Nutzotin Mountain area, it is a rock type that is considered of interest as a moderately potassic rock in a petrogenic field of lime-alkalic rocks. In his field notes Schrader describes the rock as massive, horizontally bedded flow rock, cut by nearly vertical jointing, which strikes east. It is overlain by basalts and andesites. The rock is a sparsely porphyritic aphanite of light bluish-gray color with perhaps a tinge of pink and with glassy feldspar phenocrysts. Microscropically it is seen to consist of a very fine-grained or cryptocrystalline groundmass, which makes up 70 percent of the volume. The groundmass contains numerous albite crystallites and a few augite crystallites, also some magnetite and a little quartz. Phenocrysts include a few small scraggly augite crystals and one or two small anhedral quartz crystals, but feldspar phenocrysts of several varieties which range in size from 0.1 to 2 millimeters make up about 25 percent of the volume of the rock. In order of abundance, the feldspar phenocrysts are oligoclase-albite, sanidine orthoclase, and

[38] Cross, Whitman, Iddings, J. P., Pirsson, L. V., and Washington, H. S., Quantitative classification of igneous rocks, University of Chicago Press, 1908.

[39] Mendenhall, W. C., Geology of the central copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 58–61, 1905.

[40] Moffit, F. H. and Knopf, Adolph, op. cit., p. 36.

labradorite. The labradorite phenocrysts are large, elongate, euhedral, and free of inclusions. They have shells of oligoclase-albite, to which the transition is abrupt over a somewhat corroded boundary. The oligoclase-albite crystals are also somewhat zoned and are for the most part euhedral, untwinned, free of inclusions, and abundant, but they are not as large as the other feldspar phenocrysts. The orthoclase crystals are subhedral to anhedral. Some show Carlsbad twinning and poorly developed perthitic intergrowths, and there is noticeable dispersion. Inclusions of augite crystallites may be present in the orthoclase. On a petrographic basis the rock is somewhat difficult to name. It is here called a quartz latite, and the analysis by Steiger is reprinted as D in the table. From it the norm has been recalculated by the writer and checked by J. B. Mertie. The normative classification of the rock is a liparose,[41] chemically the equivalent of many sodic rhyolites and granites. Mendenhall [42] describes a somewhat similar rock as the most acidic of the Wrangell lavas observed by him in the western part of the Wrangell Mountains.

The less abundant rock types collected by Schrader from the Jacksina drainage basin include some diabasic olivine basalts from Wait Creek, some of which are vesicular and amygdaloidal. Also, near the Jacksina Canyon, south of Wait Creek, are some dacites, nonporphyritic andesites, augite andesites, obsidian, and brownish basaltic tuffs. South of Jack Creek some of the porphyritic rocks are buff-colored felsites. From Mount Gordon Schrader collected a number of hypersthene andesites and a red, rough, massive, glassy, andesitic tuff.

GEOLOGIC HISTORY

The character, distribution, stratigraphic relations, and ages of the different rocks of the Nabesna and Chisana districts have been discussed at some length in the preceding pages. It remains to state as connectedly and as fully as possible the order and time relationships of the events that these rocks represent.

The oldest rocks of the district are schists and phyllites that crop out near the international boundary and represent original sedimentary beds and intruded igneous rocks. Their age is not known, but their metamorphism would indicate that they are older than the nearest exposures of Middle Devonian and Permian rocks. They may be of earlier Paleozoic or even of pre-Paleozoic age and the equivalents of some of the metamorphic rocks of the Yukon-Tanana region.

The Middle Devonian sedimentary beds are marine deposits in part but are associated with lava flows and pyroclastic beds, which so far as

[41] Previously reported as a kallerudose.
[42] Mendenhall, W. C., op. cit., p. 62.

is known now are like the oldest of the Permian rocks. The rocks of this district have not yielded much information about the events of Upper Devonian time, although that was a time when thick beds of limestone, conglomerate, and shale were accumulating in the sea of nearby areas.[43] More is known of the Permian period. It is characterized in this district by prolonged volcanic activity, which was interrupted twice by extended intervals of marine deposition when thick beds of limestone and of clastic materials were laid down. It was a time, moreover, when marine life flourished as at no other time in the geologic history of the district, if the abundance and variety of fossil invertebrate remains can be used as a gage for judging. The Permian ended as it began, with a great outpouring of lavas. Some of the flows show pillow structure and are thought to have been erupted into the water. Most of them, however, do not have this structure and may have been poured out on land. In any event they and the associated sedimentary rocks were elevated and folded and probably were above the sea during all of Lower and Middle Triassic time. When they were again submerged the Upper Triassic limestone was laid down on their eroded surface.

At the beginning the Upper Triassic sea was warm, and supported a warm-water fauna. In it at least a part of the massive limestone was deposited. At a later time a change occurred in the sea, and cooler waters displaced the warm water, bringing with them a different fauna adapted to the lower temperatures. Some thick beds of limestone were formed, but for the most part thin-bedded limestone with shaly partings was laid down in place of the purer massive beds. Fossils are not plentiful in most of the Triassic deposits, but where they occur they commonly are present in enormous numbers, mostly of a single species, *Monotis* (*Pseudomontis*) *subcircularis* Gabb. This fossil is found chiefly in the dark, thin-bedded argillite or limy shale but is present in some of the lower thick beds and also in the limy arkosic beds. The presence of *Monotis* in these latter beds suggests an age for them that is younger than that of most of the massive limestone, although it may possibly signify equivalence in age of the thin-bedded limestone and the arkosic rocks.

The Triassic deposits were deformed and raised above the sea only to be destroyed in large part and returned to the sea, thus repeating the story of all rocks exposed to weathering and erosion. When the limestone was again submerged and the deposition of Upper Jurassic sediments began the conditions of sedimentation had been greatly changed. Instead of calcareous deposits, mud and fine sand were laid down in thin alternating beds built up to a thickness of many

[43] Moffit, F. H., Geology of the upper Tetling River district, Alaska: U. S. Geol. Survey Bull. 917–B, pp. 129–132, 1941.

hundreds of feet. Presumably these beds indicate seasonal changes in the quantity and character of the material brought into the sea. Although the thin-bedded argillaceous and sandy beds predominate, beds of conglomerate, grit, sandstone, limestone, and shale are associated with them locally, indicating the presence nearby of a land mass that furnished the material to build them. These rocks represent Lower Cretaceous as well as Upper Jurassic time, but the relation of the two is obscure; that is, evidence has not yet been obtained to make clear whether sedimentation was continuous through these epochs or whether it was interrupted. Thick beds of coarse conglomerate within the stratigraphic section suggest the possibility of minor unconformities, which in turn imply erosion involving elevation and depression of the land. However, if erosion intervals occurred they probably were local or of short duration geologically.

The events that filled the time interval between the epochs when Lower and Upper Cretaceous beds were deposited are likewise matters of speculation. The difference in the composition, compactness, and amount of folding of the two groups of beds and the absence of plant remains and lignitized wood in the older beds suggest that the Upper Cretaceous beds were deposited under conditions wholly different from those prevailing when the Jurassic and Lower Cretaceous beds were formed. The muddy sands and abundant plant remains of the Upper Cretaceous beds suggest the shallower waters of inland seas or of river valleys and estuaries. Although a contact between the Upper Cretaceous and the older Mesozoic beds was not found it seems probable that the groups are stratigraphically unconformable and are separated in time by an important erosion interval. Apparently the Upper Cretaceous sandstone and conglomerate marks the end of marine conditions in this region, for there is no evidence that the sea has invaded it since that time.

In Cretaceous time, and possibly before the Upper Cretaceous sandstones and shales were deposited, a period of mountain building took place, which either brought into being or more probably rejuvenated the Alaska Range. The Mesozoic beds were folded, faulted, and elevated above sea level, and were thereby brought under the influence of the various agencies that destroy rocks and reduce the land surface. These changes did not take place quickly but were slow and long continued, requiring untold years for their accomplishment. Probably the disturbance with its necessary readjustment of rock masses was accompanied by the intrusion of igneous rocks and possibly the extrusion of a little volcanic material.

Earth movements and erosion did not cease in the Alaska Range with the end of the Mesozoic era. Mountain building and wasting of the land were continued in the Tertiary. During early Tertiary time interior Alaska underwent prolonged degradation, which changed much of it to a country of mature topography, but considerable relief, on which the accumulation of thick deposits of sand, shale, gravel, and, in places, important beds of coal took place locally. On the erosion surface the first of the Wrangell lavas were poured out. The extrusion of lavas and the accompanying tuffs and other fragmental rocks seems to have begun in the Eocene and has continued intermittently to the present. During this time several thousand feet of such volcanic rocks were piled up, their greatest development being in the Wrangell Mountain area. The lavas in their turn were exposed to weathering and erosion, which removed great quantities of the lavas and the older rocks and carved deep valleys in them. This took place before the invasion by ice began, which is the next outstanding event in the geologic history of the region.

The history of Pleistocene glaciation in central Alaska has not yet been completely deciphered. Increased knowledge resulting from a growing number of observations in many places suggests that the stage of glaciation which is so conspicuously indicated by morainal deposits and other evidences of the recent occupation of the valleys by ice was preceded by a stage which in some districts was more extended and produced even greater changes in the form of the land surface. However, the combined effects of the action of the ice in whatever stages of glaciation the action took place were to give to the mountains and valleys some of their most characteristic topographic features. These include nearly all the usual features of Alpine glaciation, such as rounded hill tops, truncated spurs, straightened valley walls, U-shaped valleys, moraines, till sheets, and erratic boulders. The ice accumulated to a great depth in the mountainous areas, so that only the higher peaks remained above it, and cross currents in its movement were set up by which ice from one valley invaded a neighboring valley, joining its streams and diverting its flow. Such conditions brought about a confusing distribution of rock material in gravel deposits and of erratics on hill slopes and tops and make it difficult or impossible to trace the movement of the ice at different times.

How far the ice extended from the mountains onto the lowland area of the upper Tanana Valley is still to be learned. Without doubt it extended to the lowland and spread out to some extent when it was no longer confined by valley walls. Yet, such evidence of its presence as the remnants of terminal moraines, indicating its margin, appears to be scanty or is obscured by the timber cover. On the other hand, outwash gravels from the glaciers are present in large amount and probably have a great depth in the lowland area.

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As the ice withdrew from the lower valleys to its present position, new deposits of loose material were laid down by streams and lakes or simply by the melting ice itself. Soils were formed on these deposits, where vegetation took root and established itself, thus holding the soil and contributing much to the interest of the landscape. Readjustments of drainage took place, and many streams abandoned former channels, found new channels in parts of their courses, or captured the water of neighboring streams. As a result, old channels are seen deeply cut in bedrock high on the mountain side, which evidently were once occupied by important streams but are now without water and plainly have no direct relation to the present drainage system. Numerous small lakes or ponds and poorly developed drainage in places are other evidences of the conditions brought about by the retreat of the ice.

Glaciation, the withdrawal of the ice from most of the area, and the establishment of the present drainage system may be regarded as the last great events in the geologic history of this district. Many indications support a belief that the glaciers are still in retreat, yet it is not possible to say whether this retreat is to continue to the complete disappearance of the ice or whether it may be only a temporary reversal in a new general advance. So far as the Nutzotin and Wrangell Mountains are concerned the glacial period is still in existence.

MINERAL RESOURCES

Prospecting for mineral deposits has been carried on in the headwater region of the Chisana and Nabesna Rivers almost from the day when the first stampeders crossed the Valdez Glacier and spread themselves over the Copper River Valley. As was stated previously, Brooks met such prospectors on the White River in 1899. Since then the search for valuable minerals has been continued more or less vigorously and has led to the discovery and production of both placer and lode gold but not of other minerals. Gold and copper have attracted most attention, but some less well-known minerals, such as molybdenite, occur within the district and may possibly become of commercial importance in the future.

Most of the lode and placer mines and prospects that will be mentioned in this report have been known for many years. Some of them failed early to meet the hopes of their discoverers and were given up, some have been worked out and abandoned, and others are now in operation. Nearly all have been described in previous reports[44]

[44] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 89–126, 1916.

from observations that were made when placer-mining activity was at its height and the opportunities to collect geological and historical information were more favorable than now. The following account is therefore intended to picture the present state of mining rather than to redescribe the many properties scattered throughout the district. However, it will be desirable to give attention to some occurrences of minerals that are of undemonstrated or doubtful commercial value. For the most part the facts relating to the prospects are only those that can be obtained on the ground at this time, for at such a late date it is not possible to get in touch with most of the men who worked on the individual prospects in earlier days. Even the prospects themselves may escape the attention of the field geologist who has not had previous notice of their whereabouts.

GOLD LODES

Gold-bearing lodes have been known in the Chisana and Nabesna districts for many years. Prospects of gold and of copper were discovered and had had development work done on them long before the days of the Chisana stampede in 1913. They probably outnumber the lode deposits that have been discovered since 1913, although the discovery of placer gold on Bonanza Creek brought a great number of prospectors into the country and stimulated the search for gold at that time. With one notable exception they are of low grade and have not developed into producing mines. Many of them have been abandoned. Some that attracted attention for their copper content in the days when the interest in copper was high contain gold as well as copper and may prove to have value because of that metal.

Gold mineralization is widespread and seems plainly to be connected genetically with the intrusion of granodiorite rocks that took place after the Upper Triassic limestone had been deposited, possibly in Jurassic time. The intrusion brought about pronounced alteration of the country rock locally, so that large areas are brilliantly colored. Gold and also copper mineralization was part of this process.

BEAVER CREEK

A prospect that was discovered early in the course of the mining development of the district and has long been known as the Wiley prospect is situated on the south side of Beaver Creek, nearly 1 mile west of the mouth of Ptarmigan Creek and slightly more than 3 miles from Horsfeld. At this place the sedimentary beds are intruded by a small area of gabbroic rock. Near the west end of the intrusive mass a mineralized outcrop was found, which was described in an earlier report[45] as, "an outcrop of sulphide ore 2½ feet by 5 feet in surface exposure," consisting of, "solid pyrrhotite admixed with a little chalcopyrite and minor amounts of quartz." At the outcrop the gabbroic rock is shattered and pyritized and crossed by prominent systems of fracture planes, one of which strikes N. 30°–60° W. and dips 35° SW. and another that strikes No. 10°–30° W. and dips 60° NE. The most abundant ore minerals are arsenopyrite and pyrrhotite. Quartz, calcite, and galena (?) are also present. Pyrite is present mostly as grains or small crystals disseminated in the gabbro and as small stringers. The ore minerals are accompanied by a little gold, as was shown by assays, but this gold content evidently does not encourage further exploration of the deposit at this time, for nothing is now being done with it. The last work on the property was carried on by the Acme Mining Co., more generally known as the "Simms Company," and was ended in 1938. It included a diamond drilling campaign in addition to whatever drifting and crosscutting may have been undertaken in two tunnels that have been driven on the outcrop. The tunnels are now partly caved so that their extent was not learned.

CARDEN CREEK

Development work has been done in a gold-bearing lode on Carden Creek, on the northeast side of the Nutzotin Mountains, between the Snag River and Beaver Creek. This prospect was not visited, as its location was not learned till after the geological Survey party had left the locality. The country rock is the schist or phyllite that underlies the Mesozoic shale and arkose of the ridge on the south. It is reported that a short tunnel was driven in the older rocks near the creek level and not far from a small body of gneissic granodiorite. The character of the deposit itself was not learned. Apparently little if any work has been done on this prospect for several years.

BONANZA CREEK

The Devonian and Permian volcanic rocks and interbedded sedimentary deposits of Bonanza Creek and vicinity were intruded by granodioritic rocks, which appear in a large body in the mountain west of Bonanza Creek, and also by andesitic dikes and sills and small irregular bodies distributed through the host rocks. The intrusion brought about alteration and mineralization of the country rock, which was the first stage in the formation of the gold placers of Bonanza. This mineralization is especially prominent in the walls

[45] Moffit, F. H. and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, p. 59, 1910.

of the Bonanza Creek Canyon at Bonanza and on the mountain side at the north and west. The area near Bonanza was described by Capps [46] as follows:

At the mouth of Bonanza Creek the mineralized area, which was first staked several years ago, was prospected by two tunnels each only a few feet long. For a distance of several hundred feet along Bonanza Creek the walls of the rock canyon are composed of intrusive rock, from pink to gray in color, mottled with phenocrysts of darker minerals and containing abundant pyrite, the whole being oxidized on the surface to a rusty red color. There are in places bunches composed entirely of pyrite, and some small quartz veins cut the mass. The dike cuts Carboniferous (Permian) lavas and pyroclastic rocks and apparently strikes N. 20° W. and dips about 75° N. The quartz veinlets are said to carry several ounces of gold to the ton and the whole dike is reported to be auriferous. It is said that free gold can be panned from the oxidized and decayed surface portion of the outcrop. No assay reports of the gold content were available, and too little work had been done to determine the average gold tenor of the dike, the location of the ore shoots, or the extent of the auriferous portion of the dike.

Part of this mineralized area is now included in the Erie quartz lode group, which consists of 16 claims and belongs to Earl Hirst and Sam Gamblin. In 1940 the owners were starting a tunnel some 800 feet or more above Chathenda (Johnson) Creek. They report that the veins carry silver as well as gold and that an assay of galena showed a silver content of 22 ounces per ton. The prominent minerals are pyrite and galena. Free gold was panned from the oxidized vein material.

A considerable number of other gold-bearing veins in this vicinity have been reported by Capps [47] and Pilgrim.[48] Some of them were uncovered accidentally in the placer-mining operations on the creeks and others were found through search for them on the hills. A prospect that has had considerable work done on it is located in the canyon of Chathenda (Johnson) Creek, between Dry Gulch and Bonanza. At this place two short tunnels were driven in a zone of mineralization that affects the Permian rocks and the diorites that intrude them. As described by Capps, the zone strikes approximately N. 65° W. and dips 78° SW. and extends from the canyon up the mountain on the north. The tunnels and open cuts disclose a belt of rusty, mineralized country rock, in which are quartz veins that carry sulfides and that are stained by green copper carbonate. A large group of claims had been staked on this ground, but in 1940 no development work was in progress.

[46] Capps, S. R., op. cit., p. 118.

[47] Capps, S. R., op. cit., pp. 118–119.

[48] Pilgrim, E. R., Alaska Nabesna Orange Hill copper claims: Report on cooperation between the Territory of Alaska and the United States in making mining investigations and in inspection of mines for the biennum ending March 31, 1831, pp. 66–68, 1931.

ORANGE HILL

Orange Hill is a round-topped, timber-covered knob at the east border of the Nabesna River flood plain, just below the end of the Nabesna Glacier. It is delimited on the south by Nikonda Creek, which joins the Nabesna River at this place, and on the east and north by California Creek, a small stream which separates it from the mountain on the east. The hill is about 500 feet higher than the adjacent Nabesna flood plain on the west and when viewed from the river bars is a prominent landmark because of its isolated position and color.

Moffit and Knopf [49] state that Orange Hill "consists mainly of a quartz diorite boss projecting through the gravel of the valley floor and is cut by innumerable small quartz stringers, some of them carrying pyrite and a few carrying molybdenite." The quartz diorite continues eastward from Orange Hill, forming the lower slopes of the mountain, but it is succeeded by massive Upper Triassic limestone and Permian rocks. The quartz diorite is intrusive into the limestone and has produced garnetization and other metamorphic effects similar to those at the Nabesna Mine on White Mountain.

Alteration of the limestone was accompanied or followed by the introduction of ore minerals, which include in addition to pyrite and molybdenite, already mentioned, magnetite, magnetic pyrite or pyrrhotite, and chalcopyrite. Bornite is also reported, and malachite stains the surfaces of the rocks where oxidation of the copper-bearing sulfides took place. Gold, silver, and copper are present. Pilgrim [50] states that although the chalcopyrite occurs in the quartz-calcite stringers cutting the diorite its principal occurrence is in the form of mineral grains disseminated through the diorite itself.

Orange Hill came into prominence as a likely site for gold and copper minerals early in the exploration of the district. Schrader [51] states that in 1902 a large number of claims had already been staked on California Creek and the vicinity of Orange Hill but that apparently most of them were held for their gold rather than for their copper values. In the years since 1902 these claims have repeated the cycle of changing ownership, relocation, and elimination that make up the history of mining properties in many districts. At present the ownership of the Orange Hill claims lies with the Alaska Nabesna Corporation, of which Mr. James Dulin, of Washington, D. C., is president.

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[49] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, p. 58, 1910.

[50] Pilgrim, E. R., op. cit., p. 69.

[51] Mendenhall, W. C., and Schrader, F. C., The mineral resources of the Mount Wrangell district, Alaska: U. S. Geol. Survey Prof. Paper 15, p. 38, 1903.

The Alaska Nabesna Corporation owns 18 claims, a mill site, and a homestead, all of which are patented. The claims cover Orange Hill and extend southeastward onto the ridge north of Nikonda Creek. Their relation to one another is shown in figure 5, which is based on information kindly furnished by Mr. Dulin.

The first tier of claims on the hill, next to the Nabesna River, is on the diorite intrusive, but the extension claims to the southeast follow the contact of the diorite and the massive altered limestone where contact metamorphic changes are pronounced and mineralization is heavy. Many open cuts and a considerable number of short

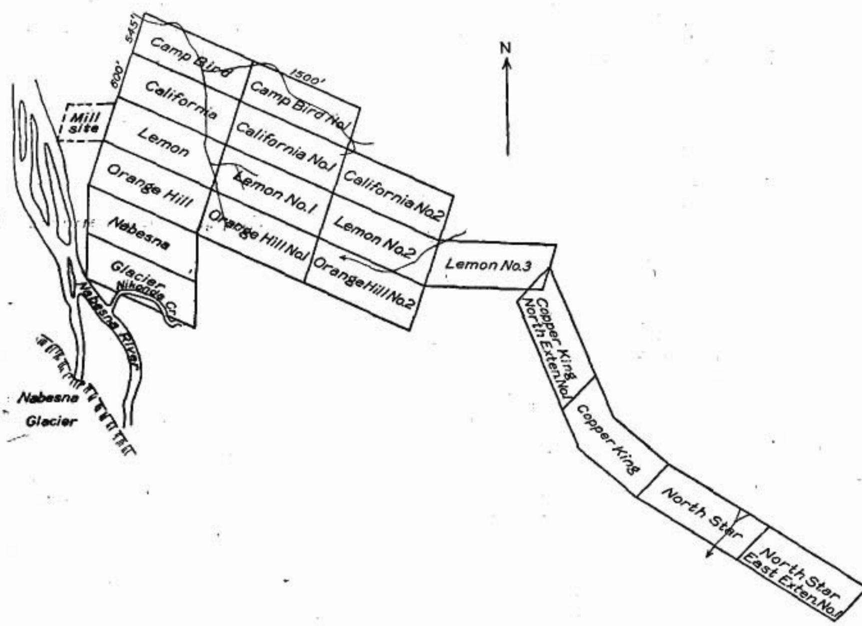


FIGURE 5.—Diagram of the mining claims of the Alaska Nabesna Corporation at Orange Hill, near the Nabesna Glacier.

tunnels have been made in exploring the claims, supplemented with many hundreds of feet of diamond drill holes. Much of the drilling was in the contact metamorphic belt and showed that the common minerals there are garnet, magnetite, pyrrhotite, chalcopyrite, and sometimes bornite. Pilgrim [52] visited the property in 1930 and described it as he saw it at that time. Since then the work of exploration has been stopped, as the low tenor in copper and gold gave little encouragement for production under present conditions. It seems

[52] Pilgrim, E. R., op. cit., p. 69.

evident that profitable operation of the property will depend on the handling of large tonnages of the ore, which is present in considerable quantity although of low grade.

NABESNA MINE

The only productive lode deposit of the district up to this time is at the Nabesna mine, which is the property of the Nabesna Mining Corporation and is situated on White Mountain, north of the Nabesna River, between Jack and Jacksina Creeks. The original outcrop of the lode, which came to be known as the Bear vein, was discovered by Mr. Carl Whitham after many years of search for ore deposits in the area east of the Wrangell Mountains. The mine was open and ready for production and the mill was put into operation in 1931; since then production from the camp has amounted to nearly $1,870,000. The Bear vein and associated ore bodies are now exhausted, but work is being continued on other undeveloped lodes belonging to the company in this vicinity.

The ore bodies of the Nabesna mine are associated with contact metamorphic deposits and represent a late phase of intrusion in which the Upper Triassic limestone was invaded by a body of quartz diorite that brought about intensive alteration in the limestone and the deposition of pyritic gold ores.

The Nabesna mine is described more fully on pages 175–195.

COPPER

The occurrence of copper at Orange Hill has been mentioned, and other prospects of copper are known, but copper prospects are not receiving attention at any place in the district at this time. Native copper was familiar to the Indians when the white men first came into the district and was collected by them from the stream gravels and from its bedrock source. Schrader [58] purchased copper nuggets from the natives on Cross Creek and states that the nuggets were reported to come from a small stream on the west side of the Chisana Glacier, about 6 miles from its foot. As far as is known all the native copper is associated with the Permian volcanic rocks and is found in them at many widely distributed localities. Many copper nuggets have been picked up on bare hilltops where the old volcanics have been exposed to weathering.

Several prospects of copper minerals were examined in the Snag River Valley, but none of them showed native copper.

[58] Mendenhall, W. C., and Schrader, F. C., op. cit., p. 40.

SNAG RIVER

Exploratory work has been done in late years on showings of copper sulfide ore at two places in the Snag River Valley. The most recent was on some prospects on the west side of a tributary that joins the East Fork 3 miles above its junction with the main river. The claims seem to be part of the property of the Hon. W. J. Sulzer, operating under the name Chisana Mines, Inc., but are sometimes known to local prospectors as the Reynolds property.

A boundary line between areas of basaltic rock on the south and black shale on the north crosses the tributary half a mile from its mouth. Here a trail leads westward from an old blacksmith shop at the edge of the creek bars to several open cuts 900 feet higher on the mountain side. These open cuts are in the amygdaloidal basalt or greenstone and expose several small veins, which contain malachite, bornite, specularite, and chalcocite with calcite. They are now partly filled with slide rock so that thorough examination of the bedrock is not possible without reopening them, but the exposed parts of the walls do not reveal any extensive or well-defined vein but rather suggest a number of small veins distributed through the fractured basalt.

Another prospect that belongs to the Chisana Mines, Inc., but is commonly referred to as the Sulzer property, or sometimes as the O'Hara property, is situated on the top of the spur, between the two forks of the Snag River. Several cabins that formed the base camp for prospecting operations but that are now partly undermined by high water were built on a small westward-flowing creek, which joins the main Snag River 2½ miles above its junction with the East Fork. A trail from these cabins ascends the creek for nearly 1 mile and then leads up a steep gulch on the northeast and crosses a low saddle south of the knob that forms the point of the spur. The summit of this saddle is only a few hundred feet south of a tunnel, which is on the slope of the mountain toward the East Fork and a little lower than the saddle. This saddle marks the east-west boundary line between southwestward-dipping Mesozoic sedimentary rocks on the south and amygdaloidal basalts on the north. Bedrock at the tunnel includes andesitic and basaltic flows resting on an andesitic flow breccia. In places a pillow structure is suggested. The tunnel is driven approximately northwest in a fracture zone in the greenstone that appears to be about parallel to the East Fork Valley. It is now partly caved but according to Pilgrim [54] had a length of 87 feet when visited by him in 1930. Twenty

[54] Pilgrim, E. R., Report on cooperation between the Territory of Alaska and the United States in making mining investigations and in inspection of mines for the biennium ending March 31, 1931, p. 75, 1931.

feet higher than the main tunnel and above it is a short prospect tunnel, or rather open cut, with walls stained with malachite and coated with copper sulfate. Some pyrite and copper sulfides are present in addition to the staining. This probably was the original outcrop of copper minerals that the tunnel was intended to explore.

The locality gives evidence of localized folding and faulting or crushing, which provided a channel in the basalts through which mineral-bearing solutions moved. The zone of fracturing extends beyond the immediate vicinity of the tunnel and is mineralized at other places, as is shown by open cuts on the knob north of the saddle.

GOLD PLACERS

Placer mining in the Chisana district is restricted to Bonanza Creek and its immediate vicinity on the north, for gold has not been found in quantities that can be mined profitably on any of the other streams. The area of gold-bearing gravels therefore is small, yet not so small as to escape some confusion in the names applied to its principal streams. In local usage, originating in the Chisana stampede, the older name Chisana became Shushanna, and the creeks Chathenda and Chavolda became Johnson and Wilson, respectively.

The real discovery of placer gold on Bonanza Creek took place in the spring of 1913, although the presence of gold was already known or suspected and two of the discoverers themselves had visited the creek the year before. The credit for the discovery of gold in the creek gravels belongs to William James, N. P. Nelson, and a Mrs. Wales, who came into the Beaver Creek Valley from the Yukon territory. After the discovery had been made and its importance was realized Nelson and Andrew Taylor, who also was on the creek, returned to Dawson for equipment and supplies. In this way the discovery became known on the outside, and a stampede of prospectors was started, which continued through 1913 and into 1914 and was accompanied by much hardship because of the shortage of food supplies and proper equipment. Most of these stampeders found no ground to stake and left soon, but a few of the fortunate ones stayed to exploit their mines.

Gold production in the Chisana district amounted to $50,000 in 1913. It reached its highest point in 1914, when it amounted to $250,000, and then fell to $160,000 in 1915, so that the first 3 years of mining yielded $460,000. Since 1915 the yearly production has varied from only a few thousand dollars to $40,000. The total production in the 27 years of mining, 1913 to 1940, amounted to approximately $970,000.

The productive gravels of the Chisana district lie within an area of old volcanics and interbedded sediments not more than 5 miles in diameter, which includes parts of the valleys of Chathenda (Johnson) and Chavolda (Wilson) Creeks and has its center in Gold Hill. The operations on the various claims in 1914 when mining activity was at its highest, were described in detail by Capps,[55] who states that an average of 325 men were employed in mining during that summer. After 1914 the production of the camp diminished quickly till it reached an imperfect equilibrium under which not over 20 to 30 men, many of whom have been on the creeks for years, are employed annually and an average of about $20,000 per year has been produced.

Bonanza Creek continues to be the chief producing stream of the area. The earlier mining was directed largely to the creek gravels, but in recent years it has been mostly in the benches or old channels, which lie at various altitudes above the creek and which for the most part are concealed from view by the loose material that streamed down over them from the mountainsides. Mining on the benches has revealed that even in such a narrow canyonlike valley as that of Bonanza Creek the stream has shifted its position many times, leaving remnants of old channels cut in bedrock as evidence of its former presence. In places two or more such channels, at different levels on the lower mountain slope, have been uncovered in sluicing the gravels. These channels bear testimony to the complicated history of the glacial retreat and probably are dependent in part on the deposition and removal of gravel deposits that occupied the bottom of the valley from time to time. Yet, whatever the manner of origin of the old channels they are now filled with frozen gravel, silt, and slide rock and carry gold in the same way as did the channel gravels of the present creek.

The Chisana district now appears to have reached a stage of mining development where new and important discoveries are not expected and production depends on the exploitation of reserves. In 1940 eighteen white persons and a number of natives were mining on different claims on Bonanza Creek and in its vicinity, but the production of gold was much below the yearly average because little rain fell in July and August and the water for sluicing was not sufficient. All the placer miners were working on claims within the drainage area of Bonanza Creek, except three who were in the valley of Glacier Creek, a tributary of Chavolda (Wilson) Creek.

Bonanza Creek cut its present channel in the floor of an old glaciated valley. Below claim No. 3 the creek runs in a narrow box canyon, which is characteristic of many mountain valleys where the headwater stretches were overdeepened by glacial erosion. From

[55] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, p. 92–118, 1916.

claim No. 3 upstream to Little Eldorado Creek the valley gradually becomes more open, and the canyon grows shallower and finally disappears. The conditions governing mining are therefore somewhat different on the upper and lower parts of the creek.

Claim No. 2 is now the most southerly claim being worked in the canyon part of Bonanza Creek. Here Earl Hirst is mining on the site of an old channel cut in the east slope of the valley wall 20 or 25 feet above the present creek. About 200 feet of the old channel remains at this place. It opens into the present canyon at both ends but passes behind a high knob of bedrock, which stands between the channel and the creek. This channel was hidden from sight till it was uncovered by mining, which began in the canyon wall but followed up the gold-bearing gravels into the hillside. The face of the cut on the east is about 50 feet high and shows rather fine, angular gravel, with a few sand beds overlain by angular glacial wash and slide rock from the hill slope. All this deposit is frozen and therefore must be thawed before it goes through the boxes. Water for thawing and sluicing is brought by a wooden flume along the canyon wall from the creek at the upper end of the claim. The gold is said to be coarser than that farther upstream and to be associated with a larger proportion of galena.

Somewhat similar conditions are met on claim No. 3, where Don Green is at work on the bench 100 feet or more above the creek and east of it. The valley is more open here, but the gravel seemingly is in an old stream meander, part of which has been destroyed by the creek as it cut its present channel. Water for mining operations is obtained in a gulch west of Bonanza Creek and is brought to the pit by an inverted siphon.

Claims No. 3B Fraction and No. 4 were being mined in 1940 by some natives. The work was on a small scale but was attended with some success. The gravels that were washed were taken from the benches on the west side of the creek at various elevations above the creek.

The most extensive placer mining operations on Bonanza Creek in recent years have been near the mouth of Little Eldorado Creek. Here the valley is more open and the hillside east of the stream rises with gentler slopes in the form of a low bench. In 1940 N. P. Nelson carried on placer mining on claim No. 6, which includes part of this bench. The first cut was approximately 100 yards east of the stream and 50 feet above it. The gravel is shallow and fine and is interstratified with sand beds. All the deposits are frozen and consequently cannot be moved easily and quickly with the hydraulic giant, as thawing requires considerable time. The gold is on bedrock, which here consists of shattered Devonian and Permian volcanics, is coarse and not much worn, and is associated with a little native silver and copper. The gold-bearing gravels appear to lie in an old channel of the creek. Unlike the gold of Bonanza Creek the gold of this channel does not contain galena and therefore is believed by the miners to have come from the Little Eldorado Valley, which has afforded some of the richest ground of the district but does not show galena in the concentrates. In connection with the question of the source and distribution of the gold it is of interest to note that pay ground has not been found on Bonanza Creek above claim No. 12 nor on Little Eldorado Creek above claim No. 3.

The remaining operations on Bonanza Creek and its tributaries include those of Anthony McGettigan on No. 12, Joe Davis on Little Eldorado Creek, and Al Peterson and Charley Hawkins on Coarse Money Creek, which is a tributary coming into Bonanza on claim No. 9. Some of these operations were in the nature of prospecting rather than mining, but all were much hindered by the shortage of water in 1940.

In the Glacier Creek Valley the operations include those of Al Wright and John Hundell on Gold Run, and of Jack Carroll on Glacier Creek, or Discovery Pup. They were small, one-man operations and like those on Bonanza Creek were hindered by the season's drought.

At the present time placer mining in the Chisana district yields a relatively small quantity of gold, which is produced by a few operators, most of whom have mined their ground in a small way for a considerable number of years. It seems probable that even if no new, richer deposits of gold-bearing gravels are discovered, the district for some years to come will have a small production, which will fluctuate somewhat according to seasonal conditions, as in 1940, or as the gold content of the gravel varies. An occasion for the revival of gold mining in the district may lie in the development of lode deposits, for the gold is of local origin and it is conceivable that some part of the lodes that gave value to the placers may still remain in the bedrock of the vicinity.

OTHER MINERALS

In some parts of the district large areas of the old volcanics have been leached and whitened or have been brilliantly colored through the agency of waters that circulated through them. This effect is especially notable in the valleys of Gravel and Baultoff Creeks, where the coloring of the rocks is vivid and many of the small tributaries are charged with iron oxide. Some of the springs are so strongly acid as to be undrinkable and corrode a hammer head immersed in them in a few minutes. Pyrite or other iron sulfides are widespread and may have been original in the volcanics, but the alteration is looked on as one of the effects of intrusion by the grandiorite or later dike rocks. Many small veins of the iron sulfides have been found in the older rocks both here and farther west in the Chisana and Nabesna areas.

A prospect of lead-zinc minerals is reported to occur in the east side of a gulch north of the Cross Creek Glacier. It was not visited but is said to show a strong mineralization and to be conspicuous from the glacier. This locality appears to be one of the few places where zinc minerals have been found.

A careful study of the heavy minerals from the concentrates of the sluice boxes on Bonanza Creek has not yet been made, but it probably would show the presence of metallic minerals that hitherto have not been reported. Among those that have been reported are gold, silver, copper, cinnabar, and molybdenite.

Molybdenite is one of the sulfide minerals found in the metamorphosed limestone at Orange Hill. So far as is known it is present in small quantity and has not been of commercial interest, although a prospect that has somewhat similar geologic relations was found on Rock Creek, a short distance north of the area shown on the map, and has had some exploratory work done on it.

GOLD DEPOSITS NEAR NABESNA

By Russell G. Wayland

ABSTRACT

The Nabesna mine is in the north border of the Wrangell Mountains, 236 miles by highway northeast of Valdez. Since operations began, in 1930, the mine has produced about $1,870,000, chiefly in gold. The principal ore body was exhausted in 1940, but summer work is expected to continue on nearby minor bodies.

The Nabesna limestone dips gently or moderately westward and is invaded by an irregular, elongated stock of quartz diorite and a number of minor dioritic and andesitic dikes. Ore bodies and tactite were formed in the limestone along the east contact of the main stock. A large area of minor intrusives and much contact metamorphism lies just south of the principal ore bodies. The dominant tactitic minerals are andradite, vesuvianite, diopside-hedenbergite, and magnetite. Tertiary lavas overlie the intrusive rocks and the limestone unconformably. The mineralized area has been exposed by erosion of the prominent limestone cliffs of White Mountain.

Three types of mineralization are present: (1) Bodies of magnetite with pyrite and calcite, (2) veins and masses of pyrrhotite with or without pyrite, and (3) veins of pyrite with calcite. Of these, only the third type has thus far been important, but a body of the second type is being prospected.

The pyrite veins are formed by replacement of the limestone, but they are localized by pre-existing fractures and contacts, especially by the contact of tactite and limestone. Most of the veins are parallel to the steep, eastward-dipping contact between the quartz diorite and limestone. Their average width is about 5 feet. Other sulfides are chalcopyrite, galena, and sphalerite. Quartz is present in the upper parts of some veins. No ore has been found below the 550-foot level of the mine. Preglacial oxidation was effective to depths of several tens of feet.

The ore is treated on a Deister table and by differential flotation. Concentrates are shipped to the Tacoma smelter.

INTRODUCTION

The Nabesna Mining Corporation owns 16 patented lode claims and holds 23 unpatented lode claims and 34 unpatented placer claims at approximately latitude 63°23′ north and longitude 143°02′ west. The property is on White Mountain, at the west side of the valley of the Nabesna River, in the White River precinct of the Third Judicial District. It is reached by a truck road 105 miles long, which branches eastward from the Richardson Highway 131 miles north of Valdez. Travel from Valdez to Nabesna by highway is possible from late May until the middle of October.

White Mountain has an altitude of 6,400 feet and presents a 1,500-foot limestone cliff as a landmark to observers in the Nabesna Valley (altitude 2,000 feet). It is one of the mountains of the Wrangell group, which in this vicinity merges with the Nutzotin Mountains to the northeast. (See pl. 5.)

Moffit and Knopf[56] visited the property of the Royal Development Co. on White Mountain in 1908. Pilgrim[57] published a sketch map of the Nabesna mine area in 1931 and gave detailed information about several mineralized outcrops. Moffit[58] visited the Nabesna mine in 1931, 1934, and 1935, and T. W. Ranta prepared a topographic map in 1938. Ranta's map with geology added from Moffit's map (pl. 2) appears in this report as plate 6. The writer spent 19 days in September 1940 mapping the underground workings and surface outcrop area in some detail. This was made possible by the hearty cooperation of C. F. Whitham, president and general manager of the Nabesna Mining Corporation, who gave the writer full access to the mine and extended the hospitality of the camp. The report and maps made by I. B. Joralemon for the company in 1939 were kindly made available to the writer, as were other private reports and records of the company.

HISTORY

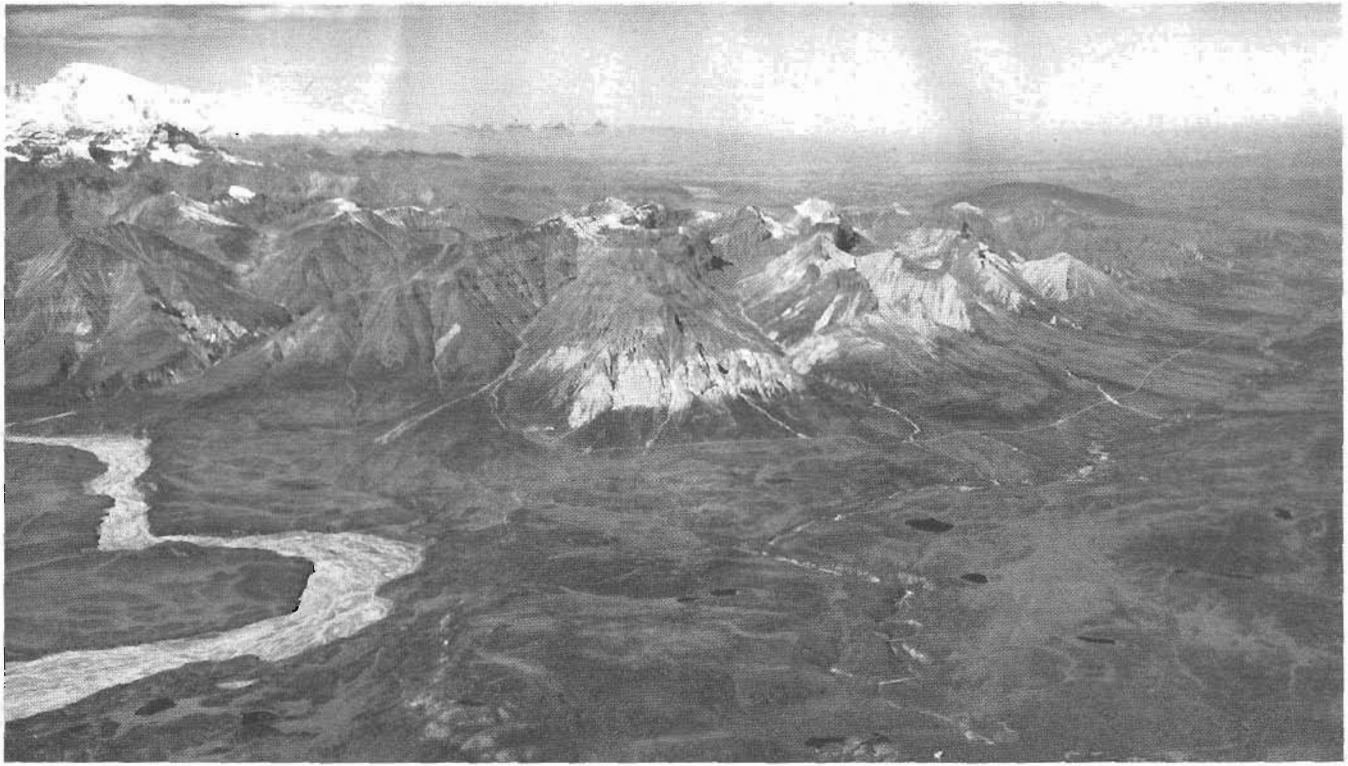
Prospectors going to the Klondike district in 1899 panned colors of gold in the gravels at the foot of the cliff of White Mountain. In 1903–1905 A. J. Fjeld and Paul Paulson located 28 claims for themselves and friends, forming an association that in 1906 became the Royal Development Co. This company, under the management of James Casey, and later J. L. Hanson, brought in a 3-stamp mill by sled from Valdez and milled 60 tons of ore in the summer of 1907 from an outcrop on Cabin Creek. The ore contained about $30 worth of gold per ton, but the recovery was only about $12 a ton. This was too low to meet the existing operating and transportation costs.

After 1907 the Royal Development Co. continued assessment work until about 1914, driving two tunnels totaling about 130 feet. The claims were then allowed to lapse. At various times other prospectors relocated them and dropped them until they were located by Mr. Whitham in 1924. The following summer a bear dug out a gopher in

[56] Moffit, F. H., and Knopf, Adolph: Mineral resources of the Nabesna-White River district, Alaska; U. S. Geol. Survey Bull. 417, pp. 58, 72, 1910.

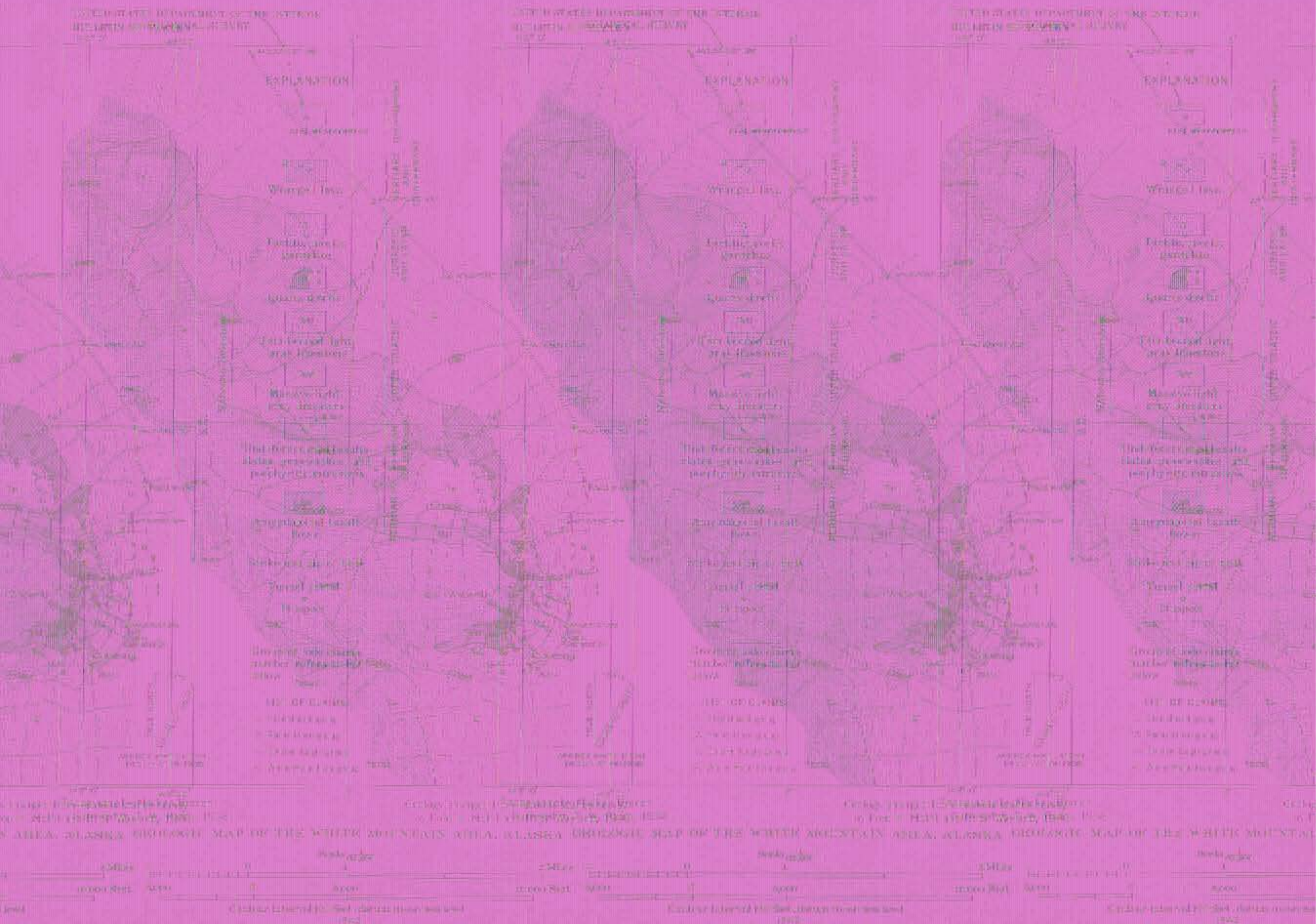
[57] Pilgrim, E. R., Nabesna Mining Corporation, Whitham group: Report on cooperation between the Territory of Alaska and the United States in making mining investigations and in inspection of mines for the biennium ending March 31, 1931, pp. 60–66, 1931.

[58] Moffit, F. H. The Suslota Pass district: U. S. Geol. Survey Bull. 844–C, pp. 159–162, 1933; Recent mineral developments in the Copper River region, Alaska: U. S. Geol. Survey Bull. 880–B, pp. 103–104, 1937.



WHITE MOUNTAIN FROM THE AIR, LOOKING WEST.

White Mountain is in the center of the picture. The Nabesna camp is at the foot of the left end of the white cliff, and the road along the valley of Jack Creek may be seen at the right. The river on the left is the Jacksina, and the prominent mountain in the left background is Mount Sanford, of the Wrangell group. The Copper River Valley is in the right background. The bedded rocks back of White Mountain are the Wrangell lavas.


EXPLANATION
GEOLOGIC MAP OF THE WHITE MOUNTAIN AREA, ALASKA

VIEW OF THE MINE AREA FROM THE NABESNA CAMP.

The mill and the aerial tramway are at the right. The dark rocks in the center are the tactite and quartz diorite of the Nugget block. The Bear block is at the right.

the moss-covered outcrop of the principal vein of the present mine, which is 1,000 feet northeast of the principal vein of the Royal Development Co. Mr. Whitham enlarged the bear's diggings and found the rich gold ore of the Bear vein. During the next 3 years he made a 50-foot cut on the vein, sank a 30-foot shaft in the outcrop, and exposed the vein at what is now the portal of the 100-foot level.

In the fall of 1929 the Nabesna Mining Corporation was formed, with Mr. Whitham as president and general manager. A tram was built to the mill site at the base of the cliff, and by the summer of 1931 a small mill was in operation and a permanent camp under construction. The scale of operation was gradually expanded until the mill was treating about 60 tons of ore a day, and the operating season reached a year-round basis in 1935. The mill recovery increased from 50 to 90 percent, and costs were reduced to permit the mining of ore carrying only $15 worth of gold to the ton. In 1933 the highway constructed by the Alaska Road Commission reached Nabesna, and thereafter transportation by dog sled, caterpillar, and airplane was superseded by trucking.

Work on the 250-foot level began in 1931 and on the 650-foot level in 1933. After 1936 almost all stoping was done between the 250- and 450-foot levels. In 1937 the important No. 49 vein was discovered. Most of the known veins were worked out by early 1939. Since that time much disappointing development work has been done, and it now appears as if the mine may be exhausted.

The gross production by the end of 1940 was $1,869,396. This figure includes some silver and a little copper recovered at the Tacoma smelter.

The initial and total capital of the company was $175,280, chiefly from local sources. All expenses of operation and expansion were met by earnings. In 1938 the company paid a dividend equal to the initial capital.

GEOLOGY

The rocks of the White Mountain area (pl. 6) include the Nabesna limestone of Upper Triassic age, which is underlain by basaltic lavas and some dark shales of possible Permian age and intruded by stocks and dikes of quartz diorite and andesite. These rocks are overlain unconformably by the Wrangell lava of Tertiary and Quaternary age. The Quaternary period is also represented by fluviatile deposits, lateral moraine, talus, and fan rubble.

NABESNA LIMESTONE

The Nabesna limestone consists of 1,200 feet of massive, light-gray, dense or crystalline limestone overlain by about 800 feet of thin-bedded, light-gray limestone. Individual beds of the thin-bedded limestone are commonly 1 to 6 inches thick and are separated by thinner layers of shale and impure limestone. Many of the uppermost beds have been removed locally at the unconformity below the Wrangell lava. The uneroded beds appear impure and shaly. No fossils have been found, which is due either to their absence or to the crystallization of the limestone during intrusion of the quartz diorite. The Nabesna limestone is the host rock of the gold deposits of White Mountain.

INTRUSIVE ROCKS

Cutting through the Nabesna limestone near the mine are an elongate stock of quartz diorite and numerous satellitic dikes of quartz diorite and andesite of varying compositions and degrees of alteration. The major body of quartz diorite is elongate north and south and is exposed for about half a mile. It is widest at its southern end, where it disappears under the gravels of Cabin Creek. North of the mine it is overlapped by the Wrangell lava. Farther north the outcrops of quartz diorite are smaller and discontinuous, and the zone of intrusive rocks passes under the gravels of Jack Creek.

The mine lies along the east border of the principal stock. Just south of the mine are a number of small irregular dikes and bodies of quartz diorite, which are accompanied by pronounced contact-metamorphic effects in the limestone. Because of the clifflike nature of the outcrop, the shape and size of many of these intrusives could not be determined directly. They were mapped with some difficulty by inspection from the mill site (pl. 7). The metamorphosed limestone usually weathers to more conspicuous and hackly outcrops than the quartz diorite.

The plutonic rocks in the mine area range in composition from hornblende-quartz diorite to quartz monzonite. The quartz monzonite has a pinkish cast. Quartz diorite rocks greatly predominate. Biotite is more abundant than hornblende in a few quartz diorites. Plagioclase crystals are much zoned, ranging from calcic andesine in the cores to oligoclase on the border. Magnetite, apatite, and titanite are common accessory minerals.

The fine-grained rocks in the mine area are porphyritic and have the composition of hornblende andesite. Phenocrysts are commonly andesine and hornblende. The plagioclase crystals are less conspicuously zoned than in the plutonic rocks, and their composition is within the andesine range. Augite appears with hornblende in some rocks. Apatite is abundant as an accessory mineral.

In the mineralized and metamorphosed zone the intrusive rocks are locally altered and mineralized. Epidote, magnetite, calcite, chlorite, and pyrite are the most abundant secondary minerals.

Northwest of Skookum Creek the basalts and shales that underlie the Nabesna limestone and the Wrangell lava are intruded by a variety of types of fine-grained and porphyritic rocks, many of them more acidic than andesites. These rocks were not studied in the course of this investigation.

WRANGELL LAVA

The Wrangell lava ranges in composition from dacite and hypersthene andesite to olivine basalt and in texture from glass to coarse porphyry.[59] The surface upon which the lava was extruded appears to have been rolling and of moderate relief. The oldest lava flowed into the valleys of the early Tertiary surface. West of Skookum Creek, beneath the unconformity, is an irregular zone of gray argillaceous material, which may be part of the weathered Tertiary surface.

STRUCTURE

The massive and thin-bedded limestones are apparently conformable. Bedding planes in the massive limestone are few but are readily discernible on close inspection. At the mine the limestone strikes N. 10°–20° E. and dips about 20° W., except in the vicinity of dioritic intrusives where attitudes are variable. Half a mile north of the mine, on the Golden Eagle claims of the company, the strike veers to the west of north and the rocks dip southwest at a moderate angle. Two miles northwest of the mine, at Skookum Creek, the limestone dips south and disappears beneath the Wrangell lava.

The mine area (pl. 8) may be divided into the Bear limestone block, which contains the principal ores, and the Nugget block, which lies south of the Bear block. Both blocks lie east of the main stock of quartz diorite. They are separated by a zone of small, irregular dikes of quartz diorite that leave the main stock and plunge southeastward.

In the Nugget block the limestone is much metamorphosed and invaded by numerous small irregular bodies of quartz diorite. Much of the limestone forms roof pendants and xenoliths (isolated blocks of inclusions) in the intrusive rocks. The xenoliths lie in random positions and attitudes. The metamorphosed limestone beds of the roof pendants dip gently westward (pl. 9, *A*). Some of the smaller intrusive bodies become sills in the thin-bedded limestones. The

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[59] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 54–62, 1905. Moffit, F. H., and Knopf, Adolph, op. cit., pp. 32–36. Moffit, F. H., Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894, pp. 92–98, 1938.

resulting upward displacement of the limestone roofs of these sills may resemble small-scale block faulting.

Most of the Bear block is massive limestone, the thin-bedded limestone south of Swede Gulch having been removed by erosion. Minor intrusives are scarce and small compared with those in the Nugget block. Andesitic and a few dioritic dikes occur here and there in the mine. Most of the andesite dikes lie in the limestone and strike a few degrees east of north and dip steeply eastward. Some pipelike bodies of andesite are developed at the north end of the 350-foot level. Small sills occur in the thin-bedded limestone north of Swede Gulch (pl. 9, *B*).

The contact surface between the limestone of the Bear block and the quartz diorite of the main stock is very irregular in detail because of numerous embayments and apophyses. In general it dips eastward about 60°, except above the 200-foot level, where it dips about 60° westward under a thick sill-like projection of the intrusive rock. Another of the larger features of the contact is an eastward-plunging bulge, or nose, of the quartz diorite underlying Swede Gulch. On the 350-foot level the contact north of the axis of this nose strikes N. 35° W., and south of the axis it strikes N. 25° E. Contact metamorphism along the quartz diorite contact is present over widths of several feet in the Bear block but is nowhere as extensive as in the Nugget block.

In the mine area there are no large faults. Fractures and minor faults of small displacement are common but not prominent. These fractures dip at moderate or steep angles and strike in many directions. Many of the mineralized fractures lie in the limestone near the quartz diorite and strike and dip parallel to the contact. Many unmineralized fractures have a strike perpendicular to the general trend of the quartz diorite. The exceptions to these generalized rules are numerous. Unmineralized fractures parallel to the main quartz diorite are fairly common. Fractures occur along the walls of many minor dikes. Where there is a roll in a contact or a termination of a dike, fractures may continue for a few tens of feet outward into the limestone.

Some of the fractures in the mine area may be minor expressions of regional adjustments, but most fracturing is ascribed to the local adjustments that took place as the quartz diorite was intruded, cooled, contracted, and settled.

CONTACT METAMORPHISM

The contact effects of the quartz diorite on the limestone of White Mountain are of two types: (1) Pyrometasomatism, the formation of contact silicate and oxide minerals, or tactite,[60] and (2) recrystallization of the limestone. Pyrometasomatism implies the addition of materials such as iron and silicon to the limestone and the removal of calcium carbonate, whereas recrystallization of the limestone requires no interchange of materials but is accomplished by heat, pressure, and aqueous emanations.

Tactite forms at or near the quartz diorite contact. At some places along the contact it is entirely missing. In the Nugget block the extensiveness of the tactite is due to the presence of many small masses of quartz diorite and suggests the possible existence of a much larger unexposed mass not far below. Xenoliths and roof pendants of limestone in the quartz diorite are especially subject to metamorphism.

The formation of crystalline limestone is much more extensive than the formation of tactite. There is more crystalline limestone on White Mountain than there is dense limestone. Some of it contains wollastonite.

CONTACT METAMORPHIC MINERALS

The contact metamorphic minerals at Nabesna are andradite, hessonite, vesuvianite, diopside-hedenbergite, epidote, penninite, thuringite, serpentine, specularite, magnetite, wollastonite, brookite, spinel, and others. This suite of minerals is much like that produced in many other localities where limestone has been invaded by quartz diorite or a similar rock.

Andradite is probably the most abundant mineral of the tactite. This garnet is especially abundant in the impure banded limestone of the Nugget block. It ranges in color from very dark brown or dark brownish green to reddish brown and even a dull, translucent greenish gray. Dodecahedral forms modified by the trapezohedron are common. Under the microscope many crystals show anomalous birefringence and zoning. Some crystals (pl. 10) have an unusually high birefringence, as great as 0.007, and show a pyramidal twinning with simultaneous extinction in alternate quadrants. A few hessonite grains were noted in a specimen of vesuvianite by Miss J. J. Glass of the Geological Survey.

Vesuvianite is abundant. It ranges in color from pale amber green and very light green to light reddish brown. The darker crystals are indistinguishable by the unaided eye from the lighter-colored crystals of andradite. Much of the vesuvianite is translucent

[60] Hess, F. L., Tactite, the product of contact metamorphism: Am. Jour. Sci., vol. 48, pp. 377–378, 1919. "Tactite may be defined as a rock of more or less complex mineralogy formed by the contact metamorphism of limestone, dolomite, or other soluble rocks into which foreign matter from the intruding magma has been introduced by hot solutions or gases. It does not include the enclosing zone of tremolite, wollastonite, and calcite."

and vitreous. The microscope shows the crystals to be twinned and to have anomalous interference colors.

Minerals of the diopside-hedenbergite series are abundant in the tactite. They range in composition from diopside-hedenbergite ratios of 4 : 1 to 2 : 3, with the diopside molecule more abundant. Some of the pyroxene may be aluminous. The color ranges from medium green and gray green for crystals high in diopside to very dark green for crystals high in hedenbergite. The crystals are commonly stubby, prismatic, and subvitreous. Some diopside-hedenbergite forms prominent dull greenish-gray shocks of radiating blades that attain lengths of as much as 2 inches.

Common epidote occurs less abundantly than garnet or diopside-hedenbergite but is widespread in the tactite and also in the altered intrusive rocks. Some crystals of epidote form vitreous elongate radiating bundles of characteristic color as much as half an inch in length.

Both chlorite and serpentine occur in minor quantities disseminated throughout the tactite, but chlorite is more plentiful than serpentine. Chlorite also occurs in the altered igneous rocks. The varieties of chlorite present are penninite, thuringite, and perhaps others. Some of the penninite is coarsely crystalline and intergrown with calcite. The thuringite is dark green, hard, and brittle. Serpentine is an uncommon microscopic constituent of the tactite, formed in part by alteration of diopside. It also occurs in some slickensided zones in altered intrusive rock.

Specularite occurs as isolated, conspicuous crystals disseminated through the tactite.

Magnetite is locally abundant. It is usually massive and dense, but some occurs in a mosaic of crystals as large as an inch in diameter. It is discussed elsewhere in this report under the heading of ore bodies.

Wollastonite, together with pale vesuvianite and a little quartz and calcite, makes up the bulk of the hard, light-colored rock locally called "silicified lime." Wollastonite is not strictly a tactitic mineral and is more abundant in the lower levels of the mine than in the Nugget area, where iron silicate minerals predominate.

Brookite was identified in a hydrothermally-altered specimen of tactite consisting mainly of calcite, quartz, epidote, and chlorite. It is a very minor constituent.

Quartz is not common in the tactite, but where present it seems to be related to the later hydrothermal alteration and mineralization rather than the contact metamorphism. It replaces calcite in preference to the silicates and oxides.

Other minerals in the tactite are uralite, titanite, apatite, spinel, limonite, gypsum, pyrite, sphalerite, and the recrystallized calcite of the original limestone.

Mr. Whitham and others[61] report the former occurrence of a small amount of "blue zircon" at certain places in the tactite.

ORE BODIES

Three types of ore bodies occur at White Mountain: (1) Bodies of magnetite with pyrite, calcite, and some gold, (2) veins and pockets of pyrrhotite with or without pyrite and gold, and (3) veins of auriferous pyrite with calcite which follow fractures in the limestone or along the intrusive contacts. Prior to 1940 only the veins of auriferous pyrite had been found to be sufficiently high grade to be workable. During the summer of 1940, however, a pyrrhotite deposit half a mile north of the present mine was sampled and found to be ore.

MAGNETITE BODIES

Magnetite is locally abundant in the Nabesna mine and elsewhere at White Mountain. Its presence renders a compass almost useless. It is a tactitic mineral like the garnets and diopside-hedenbergite, but because it generally lies on the limestone side of the tactite and is intergrown with pyrite, calcite, and a little gold, it probably formed a little later in the process of metasomatism.

Magnetite bodies were found in the mine at all elevations. One body caps No. 13 stope near the outcrop of the Bear vein. A large body that was developed on the 350-foot level 400 feet north of Swede Gulch has a very irregular shape and trends northeastward more than 200 feet. It lies in the limestone more than 150 feet away from the quartz diorite. A smaller body of magnetite occurs on the same level, 150 feet west of the large one and much nearer the quartz diorite.

On the 450-foot level is an irregular body of magnetite more than 120 feet long that is adjacent to the Swede Gulch nose of the quartz diorite and to No. 45 stope. Smaller bodies of magnetite are visible in the walls of the No. 43 and No. 35 stopes. On the 550-foot level two bodies of magnetite were found near the quartz diorite, one under Swede Gulch, the other 100 feet to the south.

Magnetite crops out in the Nugget block area, in the north fork of Swede Gulch, and elsewhere. The content of gold is commonly much below commercial grade. However, it is conceivable that bodies of magnetite impregnated with sulfides might be found that could be mined at a profit.

PYRRHOTITE VEINS AND BODIES

Underground in the Nabesna mine pyrrhotite is found only locally, but where it does occur it is more abundant than pyrite.

[61] Personal communication.

On the 350-foot level, 300 feet northwest of the Swede Gulch nose of the quartz diorite, some pockety veins and stringers in limestone were explored, but their assays showed only low values in gold. The pyrrhotite is dense, massive, and untarnished, and contains small scattered grains of pyrite and chalcopyrite. Andesitic dikes and bodies of magnetite are nearby.

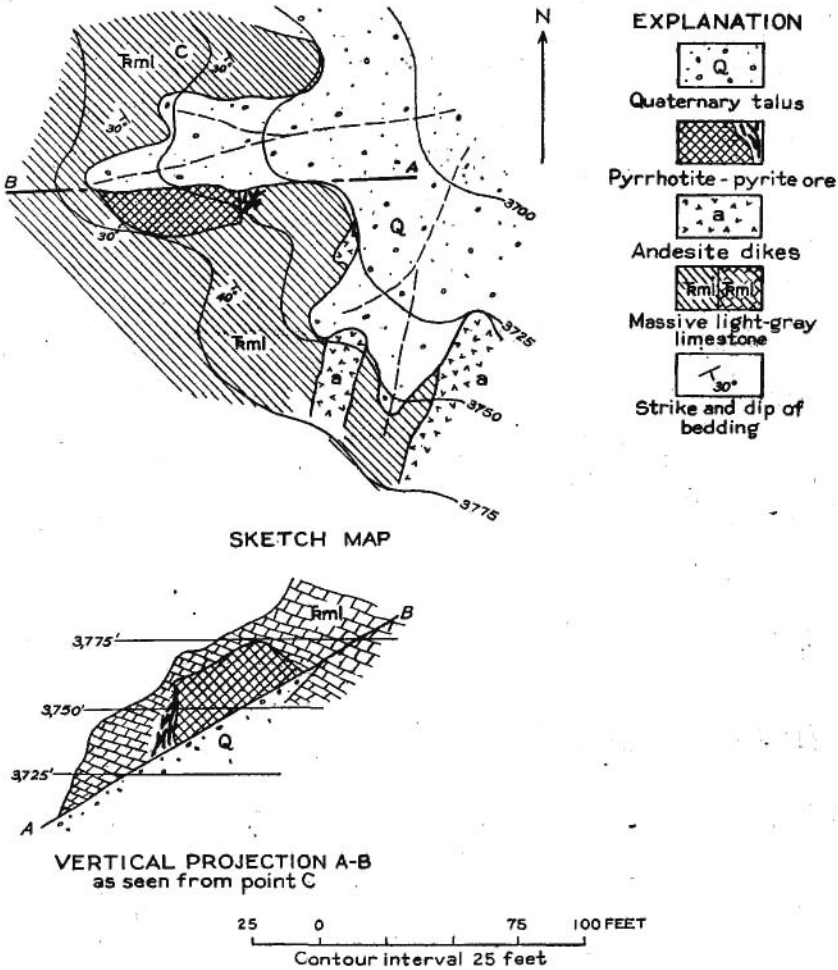
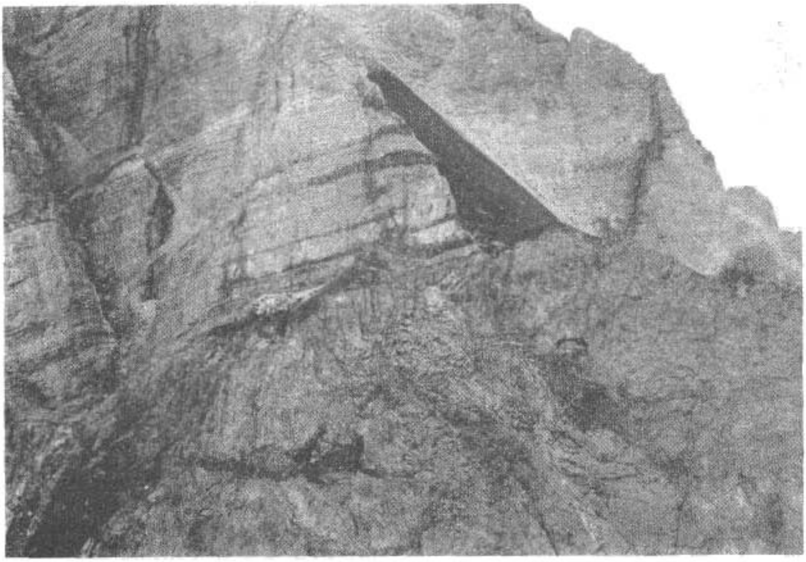


FIGURE 6.—Sketch map and projection of the Cliff vein, Golden Eagle claims.

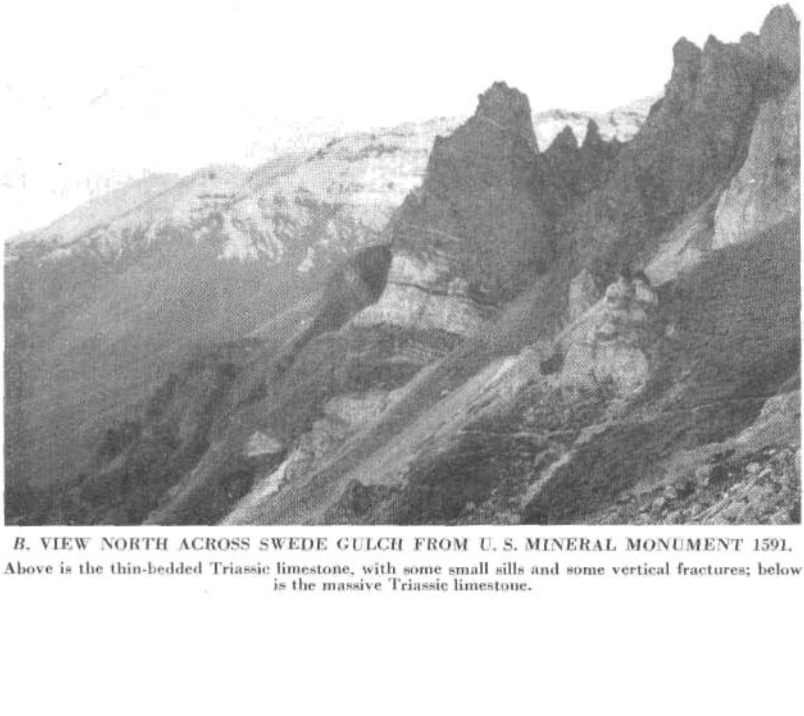
Diamond drill hole No. 68, at the north end of the 450-foot level, cuts pyrrhotite and pyrite in limestone adjacent to andesite. The gold content was considered too low for exploitation.

The Cliff vein (fig. 6) of the Golden Eagle claims of the Nabesna Mining Corporation is a massive pocket of pyrrhotite with some pyrite and marcasite. It is located half a mile north of the present



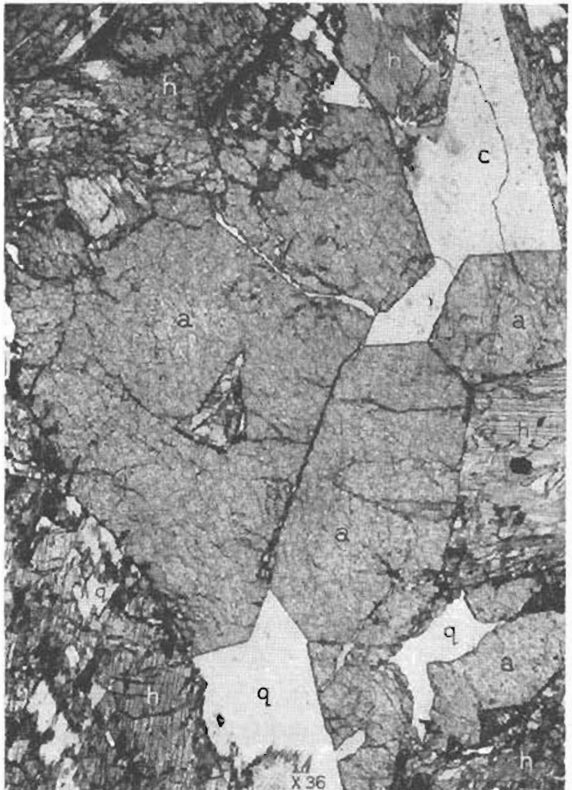
A. VIEW OF THE NUGGET AREA FROM U. S. MINERAL MONUMENT 1591.

The prominent dark outcrops are mostly tactite.



B. VIEW NORTH ACROSS SWEDE GULCH FROM U. S. MINERAL MONUMENT 1591.

Above is the thin-bedded Triassic limestone, with some small sills and some vertical fractures; below is the massive Triassic limestone.



A

B

THIN SECTION OF DIOPSIDE-HEDENBERGITE AND TWINNED ANDRADITE IN CRYSTALLINE LIMESTONE.

Diopside-hedenbergite (h), andradite (a), and quartz (q) replace the calcite (c). *A*, Ordinary light; *B*, Crossed nicols.

Nabesna mine and several hundred feet east of the closest outcrop of diorite. Andesitic dikes crop out 60 feet or more to the southeast and trend northeastward. The wall rock of the pyrrhotitic pocket is crystalline limestone. The outcrop is 52 feet long, 19 feet wide, and 34 feet high, and it appears to be about 75 percent pyrrhotite and 25 percent pyrite. A few iron-stained vuggy quartz crystals appear locally. The pyrrhotite is unusual in that it is coarsely crystalline. The crystals are as large as 2 inches in diameter and have a conspicuous basal parting. Crystals of pyrrhotite are developed in some small vugs. No sulfides other than pyrite and pyrrhotite were observed in the field, but the microscope shows the presence of a little chalcopyrite and of considerable supergene marcasite, to which the pyrrhotite is altered along an intricate network of tiny veinlets following fractures and parting planes. The average value of 14 samples of ore taken from the outcrop by Mr. Whitham was about $32 in gold a ton. The highest assay was about $85 a ton. The values are in the nonmagnetic parts of the samples.

A smaller body of pyrrhotite crops out 600 feet northeast of the Cliff vein. Other occurrences of pyrrhotite are known on the west side of the main stock of quartz diorite and are reported from the gulch of Skookum Creek.

PYRITE VEINS

The principal ores of the Nabesna mine are discontinuous veins of pyrite with calcite and lesser amounts of chalcopyrite, sphalerite, and galena. The veins have formed by replacement of the limestone along fractures and contacts. The ore shoots range in thickness from a few inches to 35 feet and average 5 to 7 feet.

MINERALOGY

Pyrite is the dominant sulfide of the Nabesna mine. Most of the pyrite is moderately coarsely crystalline, the crystals ranging from a thirty-second to a quarter of an inch in diameter. The development of crystal faces is commonly prevented by mutual intergrowth, but some of the more isolated crystals surrounded by calcite show cubic, pyritohedral, and octahedral forms. Some pyrite is very fine grained and delicately banded and is called "silicified iron" by the miners. Most pyrite forms small pockets or lenses, replacing the limestone along fractures. Some is disseminated through the tactite and the altered border zone of the intrusive rocks. In some parts of the mine the pyritized tactite and intrusive rocks are ore.

The "silicified iron" variety of pyrite is locally abundant. It makes up more than half of the ore shoot of No. 49 stope and is present in considerable quantities in No. 35 stope. It is a dull, metallic, yellowish gray color. Some of it is delicately banded, and almost all of it is very fine grained. The grain size is less than 0.0002 inch for much of the material. Because of its weak anisotropism as seen at high magnification and its association with a few small crystals of undoubted marcasite, it was thought possibly to be marcasite, but its identity as pyrite was proven by X-ray pictures taken by W. E. Richmond of the Survey laboratories. The dense pyrite seems to be contemporaneous with chalcopyrite and galena and younger than the crystalline pyrite. Some of it is older than some of the chalcopyrite, which under the microscope is seen in part as veinlets passing along the boundary between crystalline and dense pyrite.

Coarsely crystalline calcite is a common gangue mineral. Veins and bodies of pyrite and calcite within the tactite are fairly common. Small stringers of pyrite and calcite cut into the altered quartz diorite for short distances, generally following fractures.

Quartz is the chief gangue mineral in some of the smaller mineralized areas in the xenoliths and pendants of the Nugget block. It is common though not abundant in the upper parts of the Bear vein. The quartz of the Nugget area is usually much iron-stained from oxidation of pyrite, but that of the Bear vein outcrop is white, cavernous, and crumbly.

Sphalerite, galena, and chalcopyrite occur in minor quantities in the veins. In the stopes of the upper levels these minerals occur in greater quantities than at lower levels. Sphalerite and galena are generally found together as pockets and stringers cutting through pyrite or following along the edge of pyrite stringers. The sphalerite is dark brown in color. Chalcopyrite tends to be disseminated through the massive pyrite. The coarse pyrite formed first, followed by sphalerite, dense pyrite, chalcopyrite, and galena in the order named. Gold occurs with or near the later sulfides. In the Nugget area arsenopyrite, reported by Pilgrim,[62] and stibnite, reported by Whitham,[63] were not found by the writer. A little marasite occurs with some of the dense pyrite.

STRUCTURE OF ORE SHOOTS

In the Nugget block, both at the surface and underground, the ore shoots are controlled by the distribution of crystalline limestone in the xenoliths and pendants and by fractures and brecciated zones. They are small and erratic.

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[62] Pilgrim, E. R., Nabesna Mining Corporation, Whitham group: Report on cooperation between the Territory of Alaska and the United States in making mining investigations and in inspection of mines for the biennium ending March 31, 1931, pp. 60–62, 1931.

[63] Personal communication.

In the Bear block the major features of the structure of the ore shoots are best seen in the longitudinal and cross sections of the mine workings (pls. 11 and 12). The confining effect of the overhanging sill-like projection of quartz diorite is evident in the Bear vein stopes above the 250-foot level. Veins following fractures into the limestone away from all igneous contacts are illustrated by No. 13 stope. Most ore shoots in the mine follow the contact between limestone and tactite. Some ore shoots are formed by replacement along horizontal fractures. The ore body of No. 49 stope is perpendicular to the trend of the main dioritic stock, following a small transverse dike of quartz diorite eastward into the hanging wall.

Individual bodies differ much is shape, size, and tenor. Generalizations that may be made are: (1) The largest and most continuous ore bodies lie above the 250-foot level, (2) with the exception of that of No. 49 stope, all important ore shoots have been found south of the Swede Gulch nose of quartz diorite, and (3) little commercial ore has been found below the 450-foot level.

DESCRIPTIONS OF INDIVIDUAL ORE SHOOTS

The following descriptions are based in large part on oral statements on mining history made by Mr. Whitham to the writer.

The Bear vein stope extends about 320 feet horizontally and 250 feet vertically. The ore shoot continues downward through Nos. 31 and 32 stopes to the 350-foot level. Above the 200-foot level the ore shoot dips westward 60° under an overhanging sill-like projection of quartz diorite. Below the 200-foot level it dips eastward 60° with the main contact of the quartz diorite. The western wall of the shoot is either quartz diorite or tactite, and the east wall is limestone. Above Nos. 4 and 5 raises, some of the quartz diorite is altered and sufficiently auriferous to be mined. The high grade ore shoot of the Bear vein stope consists of pyrite, some disseminated chalcopyrite, and a little galena along the walls. The greatest thickness is at the change in direction of dip at the 200-foot level, where it reaches 35 feet or more. The ore shoot becomes thin and low grade at its south end. At its north end it terminates abruptly. Gouge, mud seams, and slickensides gave trouble in mining. The ore shoot crops out at the surface near the portal of the 100-foot level and at the glory hole where the original discovery was made. The sulfides of the ore shoot were found to continue nearly to the surface. Anglesite, cerussite, and quartz constituted the ore at the surface. A little free sulfur was also present in this surficial ore. Iron oxides derived from the oxidation of the pyrite of the ore shoot were redeposited, principally in the limestone wall rock, and do not extend much below the 100-foot level. Quartz is uncommon below the 100-foot level.

North of the Bear vein, in the upper levels, is the vein of No. 13 stope, which differs from the Bear vein in that it follows a vertical fracture in the limestone rather than the recessed contact of the quartz diorite. The south end of the ore shoot terminates 150 feet above the 250-foot level, spreading to a 15-foot width under the overhanging quartz diorite and a small body of magnetite. The north end of the ore shoot crops out at the surface in Swede Gulch, about 150 feet above the 250-foot level. The ore shoot averages 5 or 6 feet in width. In places it was found to be nearly solid galena. Ore values were as high as $100 a ton. The wall rocks and some of the ore are much oxidized. A few blocks of solid clear ice were found.

The veins of Nos. 31 and 32 stopes at the south end of the 350-foot level represent the lower part of the Bear vein and follow the contact of the tactite and limestone. The vein of No. 32 is wide and rich just below the 250-foot level. It becomes much narrower within 30 feet, although the tenor of the ore remains constant. Some of the pyrite is loosely banded and in blasting is reduced to a sand. The ore shoot of No. 31 stope is an irregular pipelike body of coarse, compact, crystalline pyrite of moderate tenor.

No. 35 stope is in the limestone near the tactite and quartz diorite. In general its ore shoot plunges eastward. The north end of the shoot is very irregular in shape. The south end flattens and follows a horizontal seam in the limestone. The ore is pyrite of average tenor. Some of the pyrite breaks down to a sand when blasted. Other pyrite is compact, and some is very fine-grained and delicately banded. A little magnetite was found near the ore shoot.

The vein of No. 43 stope is similar in its mineralogy and irregular shape to that of No. 35 stope. At its north end magnetite bodies underlie and overlie the ore shoot. The tenor of the ore is average or lower, and the width is about 10 feet. The shoot dips about 60° E.

Nos. 45 and 53 stopes are on an irregular, tabular ore shoot of low-grade, pyritic ore, which averages about 6 feet in width and dips about 60° E. or less. Magnetite occurs at some places along the walls and in parts of the ore shoot. No. 51 stope is on a small, low-grade pocket of pyrite. The ore shoots in the stopes of the lower levels are characterized by low values in gold, erratic mineralization, irregular shape, and by less sphalerite, galena, and chalcopyrite than in the stopes of the upper levels.

The vein of No. 49 stope was discovered in 1937 and was mainly responsible for the profitable operation during the seasons of 1937 and 1938. It differs from other veins of the lower levels in a number of respects. Its trend, as mentioned above (p. 187), is perpendicular to the trend of the quartz diorite. It follows the north wall of a small, east-west vertical dike of quartz diorite that lies northeast of the Swede

Gulch nose of the main stock. The small dike terminates upward at about the 250-foot level, but the vein continues for 100 feet, splitting into two parts as it follows fractures upward in the limestone. The bottom of the ore shoot is about 20 feet below the 450-foot level. The thickness of the ore shoot averages 4 or 5 feet, and the greatest horizontal length is about 250 feet. More than half of the sulfide of the ore shoot is very fine-grained, delicately banded pyrite. The other sulfides are crystalline pyrite, sphalerite, chalcopyrite, and especially galena. The quantities of sphalerite, chalcopyrite, and galena present are greater than in other stopes of the lower levels and comparable to those in the Bear vein and No. 13 stopes. More than 90 percent of the gold content in the ore was recovered on the concentrating tables.

OXIDATION

Sulfides crop out at the surface in several mineralized areas, and include the Cliff vein of the Golden Eagle claims and some veins of the Nugget area. These outcrops are on steep hillsides where present erosion is rapid or glacial erosion has exposed them. The pyrrhotite and pyrite of the Cliff vein are comparatively fresh; marcasite alters the pyrrhotite along an intricate network of fractures, and a little limonite stains the surface or the fractures near the surface that are followed by the marcasite.

The Bear vein and some veins of the Nugget area are partly oxidized. Extensive weathering of the Bear vein is restricted in depth to a few tens of feet, but locally oxidation extends to more than 350 feet. The original outcrop of the Bear vein is described by Pilgrim [64] as follows:

> "At the outcrop the vein filling is soft and crumbly and contains some pieces of flinty quartz that carry pyrite. Other vein minerals are fine crystals of pyrite, cerussite, marcasite, and anglesite. The vein is light gray in color with a dark gray streak near the middle that contains considerable cerussite and anglesite. The vein shows on the surface a width of from 3 to 4 feet. Pannings taken from this soft vein filling show considerable free gold. The gold is irregular in shape, but not angular. It is stained a dark color."

Assays that showed values of 10 to 20 ounces of gold a ton were fairly common in the lead carbonate ore. One assay reported by Pilgrim showed 49.74 ounces of gold, 73 ounces of silver, and 6.11 percent of lead in a 5-inch dark streak near the hanging wall of the Bear vein outcrop.

Much of the iron derived from oxidation of the pyrite near the outcrop of the Bear vein was deposited as limonite in the altered limestone walls of the vein. With the limonite is considerable gypsum, occurring as scattered rosettes of selenite crystals or as veinlets of satin spar. Malachite and some azurite occur locally as stains

[64] Pilgrim, E. R., op. cit., p. 63.

and encrustations in the limonitic wall rock. Alteration of the wall rock extends below the 100-foot level, although the ore shoot at this level is said to have consisted mostly of the primary sulfides.

On the 250-foot level neither the sulfides nor the calcite of the gangue and wall rock are oxidized, except along a few fractures where limonite has formed. At the north end of the 350-foot level are some vugs several feet in diameter, which were formed by local solution along fractures in crystalline limestone. Loosely consolidated acicular crystals, which form a coat on the walls of the vugs an inch thick, were identified by J. J. Fahey of the Survey Chemical Laboratories as the hydrous ferric sulfate fibroferrite ($Fe_2(SO_4)_2$-$(OH)_2 9H_2O$). The color of the crystals is pale greenish yellow, almost white. On exposure to air the fibroferrite slowly turns brown, and in oxygenated waters it decomposes rapidly to limonite.

The oxidation of the Nabesna ores may have taken place at various times. It may have started during the period of erosion after the intrusion of the quartz dioritic stock and before the outpouring of the lava. It may have occurred during the period of erosion following extrusion of the lavas, perhaps during some of the longer and warmer interglacial stages of the Pleistocene epoch. Present rock temperatures are 1° or 2° below freezing. Surficial waters freeze on entering fractures and mine openings. Moisture in the air in underground openings condenses to tabular ice crystals 2 or 3 inches across, which grow edgewise from the walls and give a striking "crystal palace" effect. Hence it appears that no oxidation of significance can occur under present climatic conditions. It is questionable that ground temperatures were above freezing for sufficient periods of time during interglacial stages to have allowed the oxidation. Because extrusion of lavas in other parts of the Wrangell Mountains is known to have continued into the Quaternary period, the length of time following the exposure of the ores by erosion of the lavas at White Mountain may not have been long. The writer suggests that most of the oxidation of the ores took place before the extrusion of the lavas.

GENESIS

In the preceding part of this report the principal characteristics of the rock formations, structure, rock alteration, and vein materials have been set forth. On this fragmentary evidence, interpreted in the light of broader geologic concepts, the following discussion of the origin of the deposits is based.

The principal ore veins are developed in the limestone outside of the tactite. They show obvious structural control by fractures that postdate the pyrometasomatism. Moreover, some ores cut through the tactite locally as veins and stringers. The mineral assemblage of the ores is typical of that of many hypothermal and mesothermal deposits. The solutions which formed the ore shoots appear to have originated deep in the core of the quartz diorite. It is therefore concluded that the Nabesna ores have formed later and at lower temperatures than the tactite. In this respect the Nabesna deposit differs from some pyrometasomatic deposits where sulfide minerals are essentially contemporaneous with the silicates and oxides of the tactite and all minerals form at temperatures comparable to those of crystallizing acidic magmas.

The pyrometasomatism probably took place during and shortly after the intrusion of the quartz dioritic magma and the andesitic dikes. It continued as the magma cooled and the upper part or hood of the stock crystallized. At the same time much of the limestone beyond the zone of pyrometasomatism was being recrystallized under the influence of heat and pressure and with the aid of aqueous emanations from the magma. As the magma continued to cool and crystallize the hood became much thicker and pyrometasomatism less effective.

Presumably when the quartz diorite was almost completely crystallized the part of it that remained liquid was highly aqueous and under great vapor pressure, owing to the removal by crystallization of the anhydrous minerals of the quartz diorite. Emanations from this residual magma rose through fractures produced by their own pressure and by contraction of the hood. As they rose they condensed and cooled, and especially where the fractures passed into the limestone there was a reaction that resulted in the deposition of the ores.

OPERATIONS

MINING

The open, underhand stoping method is employed at the Nabesna mine. A stope raise is driven through the ore shoot, and mining is begun a few feet below the sill of the level above, or at the top of the ore shoot. The broken ore is hand trammed on the level below from a chute at the bottom of the stope raise and is delivered to an ore pass. On the main haulage levels it is hand trammed again to the portals, where it is carried by aerial tramway to the mill at the base of the cliff.

In most of the stopes the walls stand well. Some sloughing occurred in stopes above the 250-foot level. The stopes above the 100-foot level are filled. Most stopes of the lower levels are standing empty.

A historical summary of development work, including diamond drilling, is given in the following table.

Summary of development, in linear feet

[Data mostly from annual reports of the Nabesna Mining Corporation]

Year	Surface	100-foot level		250-foot level		350-foot level		450-foot level		550-foot level		650-foot level		Total	Diamond drill holes	
		Drifts	Raises	Drifts	Raises	Drifts	Raises	Drifts	Raises	Drifts	Raises	Drifts	Raises		Feet	Levels
1925–29	80													80		
1930		150	25											175		
1931		70	95	452										617		
1932				150	[1] 262									412		
1933				64	[1] 98							370		532		
1934					830							1,010	28	1,868	585	650, 250
1935				243	766	382	[2] 191		[2] 100		[2] 100	[2] 308	[2] 233	2,323	1,045	250, 650, 350
1936	[3] 125				50	715	821	670	505	116	162	39		3,203	1,292	350, 450, 650
1937	[3] 163			[4] 255		308	75	378	682	161				1,980	695	350, 450
1938				[4] 820	[4] 40	754	398	132		199	120		126	2,589	1,840	550, 250, 350, 450
1939				[4] 638	[4] 85	499	196	69		63	160			1,630	3,364	350, 250, 450, 650
1940					25	131	121		15			100		392	1,178	650, 350
Total	368	220	120	2,522	2,156	2,849	1,802	1,247	1,202	559	542	1,827	387	15,801	9,999	

[1] Includes sublevel drifts. [2] Adjusted by Wayland. [3] Nugget tunnel. [4] Nugget crosscut.

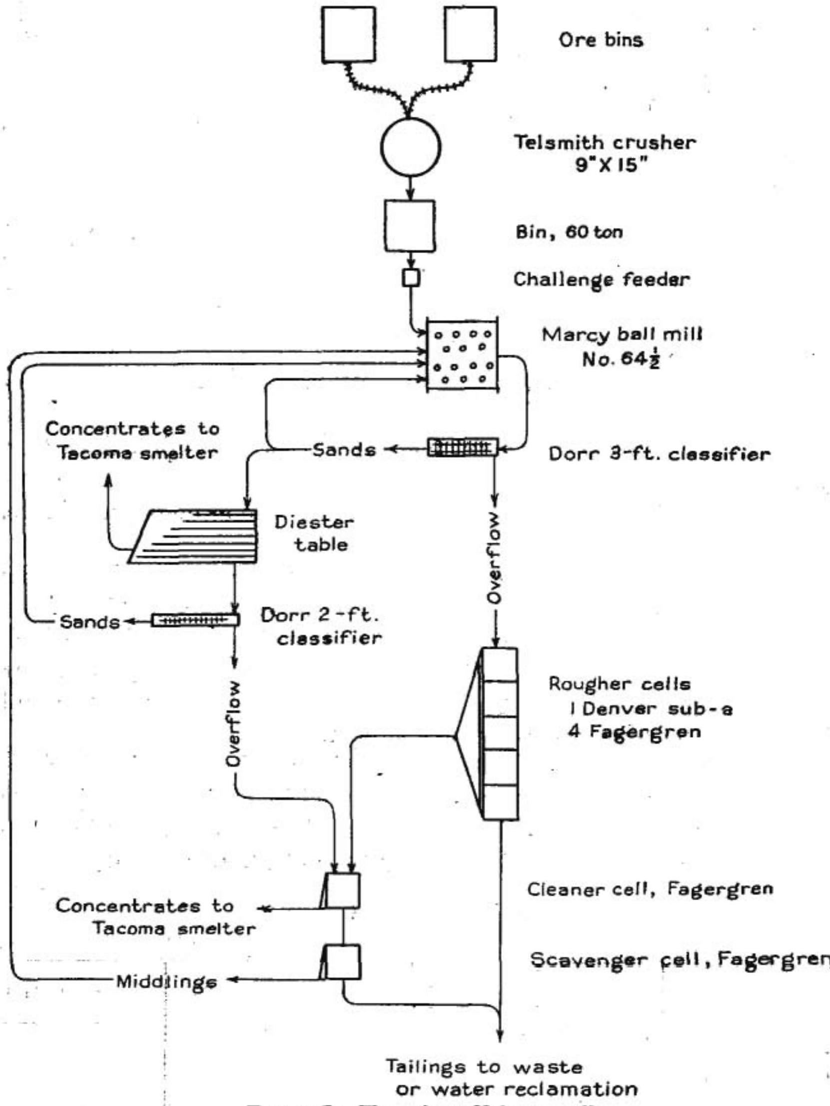

FIGURE 7.—Flow sheet, Nabesna mill.

MILLING

Until 1933 the mill consisted primarily of a small Hardinge ball mill, two sand tables, and three slime tables. Amalgamation of concentrates from the sand tables was attempted but was unsuccessful because of an oxide film on the gold, and because, according to Mr. Whitham,[65] anglesite went into the amalgam with the gold, forming a gold-lead amalgam. The concentrates from the slime tables were stored to await lower freight costs.

[65] Personal communication.

In 1933 a Kraut flotation unit of six cells was added to the circuit, with only moderate success. Denver Sub-A and Fagergren cells were substituted in 1934–35 for the Kraut cells, and the use of slime tables was discontinued. A larger Marcy ball mill replaced the Hardinge mill.

In 1935 a cyanide leaching plant was added in order to increase recoveries, to treat stored tailings, and to save shipping charges on concentrates. The mill was shut down 4 months in 1936 while this was converted to a continuous-agitation cyanide plant. The bullion produced by the cyanide unit was between 800 and 900 fine.

Cyanide operations gave considerable trouble. By the end of 1938 most of the stored tailings had been treated. Technological developments in selective flotation, coupled with high table recoveries, made abandonment of the cyanide unit feasible. The present flow sheet (fig. 7) is according to Mr. August Sundstedt,[66] mill superintendent.

In winter time the water supply is only about 15 gallons per minute. Power is supplied by Diesel engines.

From the beginning of operations the sand tables have yielded the major recovery, which has ranged from 60 to 90 percent. Ores from the stopes above the 100-foot level gave streaks of anglesite an inch wide on the tables. Later, ores from Nos. 13 and 49 stopes gave galena streaks. The Tacoma smelter recovered some values in copper and silver from the table and flotation concentrates.

A historical summary of milling operations and production is given in the following table. The tonnages treated in 1937 and 1938 include sizable quantities of old tailings. Some tailings were treated in other years. The recovery on tailings amounted to 50 to 60 percent.

Summary of milling and production

[Data from annual reports of the Nabesna Mining Corporation]

Year	Days of milling operation	Tons milled	Average assay value per ton	Percent recovered	Gross production [1]
1931	60	1,302	$90.00	50.99	$60,759.53
1932	86	2,022	83.68	81.67	131,978.54
1933	119	2,874	53.54	81.40	141,649.68
1934	170	9,955	32.86	74.60	244,073.69
1935	295	16,443	19.52	77.03	247,259.38
1936	224	11,653	17.99	90.88	190,513.11
1937	285	[2] 16,117	[2] 18.00	68.33	198,249.04
1938	313	[3] 18,026	[3] 33.65	86.66	525,689.98
1939	124	5,758	18.52	88.22	94,092.24
1940		[4] 4,074	[4] 11.00	78.42	35,130.81
Total		88,224	26.59	79.68	1,869,396.00

[1] Includes small values in silver and copper.
[2] Includes 7,327 tons of tailings at $14.49 per ton.
[3] Includes 5,801 tons of tailings at $14.69 per ton.
[4] Includes 2,102 tons of tailings at $6.48 per ton.

[66] Personal communication.

FUTURE OF MINING

Since completion of mining in Nos. 49 and 53 stopes early in 1939 further exploration has gone apace. The 350-foot level was driven northward and westward. The 250-foot level was driven through the Nugget block to the surface at Cabin Creek. Extensive diamond drilling probed the 250-, 350- and 650-foot levels eastward into the limestone, northward along the intrusive contact, southwestward into the pendants of the Nugget block, and westward well into the northern part of the quartz diorite. Unfortunately no ore was found during the seasons of 1939 and 1940, but further exploration along pyrite seams and dike contacts might possibly lead to other discoveries in the mine area. The company developed the pyrrhotitic pocket known as the Cliff vein of the Golden Eagle claims during the season of 1941.

Mineralization of the pyrite, pyrrhotite, and magnetite types is known in many places near the quartz diorites of White Mountain. In most outcrops where gold is present the size of the exposed mineralized area is small or the tenor is low. However, it is conceivable that ore bodies of sufficient size and grade to be mined at a profit may be found.

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