GEOLOGY OF THE ALASKA-JUNEAU LODE SYSTEM, ALASKA

By

Wm. S. Twenhofel

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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ABSTRACT

The Alaska-Juneau lode system for many years was one of the World's leading gold-producing areas. Total production from the year 1893 to 1946 has amounted to about 94 million dollars, with principal values in contained gold but with some silver and lead values. The principal mine is the Alaska-Juneau mine, from which the lode system takes its name.

The lode system is a part of a larger gold-bearing belt, generally referred to as the Juneau gold belt, along the western border of the Coast Range batholith.

The rocks of the Alaska-Juneau lode system consist of a monoclinal sequence of steeply northeasterly dipping volcanic, slate and schist rocks, all of which have been metamorphosed by dynamic and thermal processes attendant with the intrusion of the Coast Range batholith. The rocks form a series of belts that trend northwest parallel to the Coast Range. In addition to the Coast Range batholith lying a mile to the east ofthe lode system, there are numerous smaller intrusives, all of which are sill-like in form and are thus conformable to the regional structure.

The bedded rocks are Mesozoic in age; the Coast Range batholith is Upper Jurassic and Lower Cretaceous in age. Some of the smaller intrusives pre-date the batholith, others post-date it. All of the rocks are cut by steeply dipping faults.

The Alaska-Juneau lode system is confined exclusively to the footwall portion of the Perseverance slate band. The slate band is composed of black slate and black phyliite with lesser amounts of thin-bedded quartzite. Intrusive into the slate band are many sill-like bodies of rocks generally referred to as meta-gabbro.

The gold deposits of the lode system are found both within the slate rocks and the meta-gabbro rocks, and particularly in those places where meta-gabbro bodies interfinger with slate. Thus the ore bodies are found in and near the terminations of meta-gabbro bodies.

The ore bodies are quartz stringer-lodes composed of a great number of quartz veins from 6 inches to 3 feet wide and extending along their strike and dip for several tens to hundreds of feet. In addition to quartz the only other vein gangue mineral is ankerite. It occurs in small amounts along the borders of the quartz veins. Metallic vein minerals, in addition to native gold, are, in order of decreasing abunddance, pyrrhotite, galena, sphalerite, and arsenopyrite. In the aggregate the metallic minerals comprise only 1 to 2 percent of the total amount of vein material.

The wall rock, particularly the meta-gabbro, was profoundly altered by the vein-forming processes. The principal effects on the metagabbro were the addition of large amo unts of soda, potash, titanium, carbon dioxide, and phosphorous, and the removal of considerable quantities of iron, magnesia, lime, and combined water. Silica also may have been decreased. The mineralogical changes involved in the alteration were the development of biotite and ankerite at the expense of original hornblende and feldspar, resulting in a brown-colored biotite- and ankerite-rich rock. The slates are relatively unaffected by the vein-forming processes.

Because of their small size, relatively low grade, and discontinuity, no attempt has been made to mine any individual vein. The prevailing practice has been to mine large blocks of ground by a system of modified block-caving, followed by hand sorting to remove the barren country rock from the gold-bearing quartz prior to milling.

INTRODUCTION

Ever since 1880, when gold was first discovered in Gold Creek near the present city of Juneau and until all mining operations ceased in 1945, the gold mines in the vicinity of Juneau have been among the largest in the world. The two principal groups of mines have been those of the Treadwell group and those of the Alaska-Juneau lode system. The former is on Douglas Island across Gastineau Channel from Juneau and was comprised of the Ready Bullion, Alaska-Mexican, Seven-Hundred Foot, and Alaska-Treadwell mines. The latter group is on the mainland east of Juneau and was comprised of the Perseverance, Alaska-Juneau, and Ebner mines, all of which mined ore from the Alaska-Juneau lode system.

These two groups of mines have been the most productive of a poorly defined gold-bearing region extending from Windham Bay on the southeast to 4 or 5 miles north of Berners Bay on the northwest; this region is generally known as the Juneau Gold Belt. The term belt is applied as the region lies within a group of metamorphic rocks that generally parallels the coast line and the southwestern border of the Coast Range batholith. The total production of the Treadwell group of mines is estimated at approximately $67,500,000 for their productive history during the period 1882 to 1926. The total production of the group of mines within the Alaska-Juneau lode system is estimated at approximately $92,000,000 for their productive history during the period 1893 to 1947.

Although many geologists and mining engineers have studied the gold deposits of the Juneau Gold Belt the only comprehensive report covering the geology and ore deposits is by Spencer (1906), who examined the area in the field in 1903 and 1904. In 1916 the U. S. Geological Survey assigned A. C. Spencer and H. H. Eakin to a more detailed study of the Juneau Gold Belt, particularly in the immediate vicinity of the Treadwell and Alaska-Juneau mines. Their work lasted one season but because of World War I the report on their work was delayed and in 1921 Eakin again visited the area to assemble more data that had been revealed by subsequent mining operations. The results of the 1916 and 1921 work of Spencer and Eakin have not been published.

After World War II, the U.S. Geological Survey initiated a new study of the Juneau Gold Belt. The area selected for field study and examination was that portion of the Belt extending from Taku Inlet northwest to 4 or 5 miles north of Berners Bay: i.e. the northern half of the Juneau Gold Belt. W. S. Twenhofel and F. A. Stejer were assigned to this tudy and they commenced field work in the summer of 1946.

It is planned that Stejer will prepare an official Geological Survey report covering his area, and that the author will prepare a similar report covering the area of his responsibility. Much, but not all, of the data in this preliminary report will be included in the more comprehensive report that is being prepared for the Geological Survey.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the wholehearted cooperation of the Alaska-Juneau Gold Mining Co. throughout the course of the investigation of the Juneau Gold Belt. Prior to the start of the Geological Survey project the Alaska-Juneau Gold Mining Co. offered to make available to the Geological Survey all of their records, maps, and reports. These have been invaluable and without them it would have been almost impossible to prepare this report. Particularly useful have been the several geologic reports prepared by Livingston Wernecke. Mr. Wernecke served as consulting geologist for the Alaska-Juneau Gold Mining Co. for many years prior to his death in an airplane accident in 1941. Mr. Joseph M. Williams, Resident General Manager and Mr. Eugene Nelson, Asst. General Manager gave freely of their time in discussions of the geology of the mine and also made available underground transportation to the Geological Survey personnel engaged in underground mapping.

During 1946 and 1947 F. A. Stejer assisted the author in the field investigations, and his able work is acknowledged. However, the author accepts full responsibility for the ideas, opinions, and observation expressed herein.

The first published report on the geology of the Juneau Gold Belt is that by Spencer (1906) based on field work in 1903 and 1904. His report is still the most comprehensive report on the area. At the time of Spencer's work the Alaska-Juneau mine was just getting into operation and his description of the geology of the Alaska-Juneau lode system is necessarily sketchy. Since Spencer's work virtually nothing has been published on the geology of the Alaska-Junea lode system. The September 1932 issue of the Engineering and Mining Journal was devoted to a discussion of the Alaska-Juneau mine. Wernecke (1932) contributed to the issue with a description of the geology of the north ore body as it was then known.

Several unpublished reports of a private nature have been prepared on the Alaska-Juneau mine. These have been consulted in the preparation of this report. They include reports by Wernecke (1918), Ball (1916), Graton (1916), and Rogers (1916).

The Geological Survey manuscript report by Eakin (1922) also was freely consulted.

A selected bibliography is given on the following pages. It is divided into two parts. The first part lists articles dealing with the geology of the Alaska-Juneau lode system and the second part lists articles of a more general nature and those concerned with mining and milling methods.

Selected Bibliography

Geology

1. Ball, Sidney H., 1916, Geological report upon the property of the Alaska-Gastineau Mining Company near Juneau, Alaska, unpublished private report, Sept. 14.

2. Eakin, H. M., 1922, Geology and ore deposits of Juneau, Alaska, unpublished Geological Survey manuscript report.

3. Graton, L. C., 1916, Results of microscopical examination of rock and ores from the Juneau region, Alaska, unpublished private report for the Alaska-Gastineau Mining Co.

4. Rogers, A. H., 1916, Report on the ore reserves of the Alaska-Gastineau mine, unpublished private report.

5. Spencer, A. C., 1906, The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287.

6. Wernecke, Livingston, 1918, Geology of Alaska-Juneau lode system, unpublished private report, July 1.

7. Wernecke, Livingston, 1932, Geology and ore possibilities of the Dora-Hallum groups of mining claims, and a review of the north ore body of the Alaska-Juneau mine, unpublished private report.

8. Wernecke, Livingston, 1932, Geology of the ore zones of the Alaska-Juneau enterprise: Eng. and Min. Jour., vol. 133, no. 9, pp. 493-499.

9. Wernecke, Livingston, 1932, Geology and ore reserves of deep levels of north ore body and above no. 4 level of south ore body, unpublished private report.

General, mining, and milling

10. Anonymous, Sept. 1942, Alaska-Juneau - Secondary blasting, bulldozing practice: Mining World, pp. 9-14.

11. Bradley, P. R., March 1924, Estimation of ore reserves and mining methods in Alaska-Juneau mine: A. I. M. E., Trans., no. 1329

12. Bradley, P. R., 1936, Alaska-Juneau deep-level mining: Mining and Metallurgy, vol. 17, pp. 391-392.

13. Bradley, P. R., 1936, Barges for waste disposal: Eng. and Min. Jour., vol. 137, pp. 450-452.

14. Clausen, V. C., 1921, Alaska-Juneau mill flow sheet: Min. and Sci. Press, vol. 122, pp. 625-634.

15. ~~[illegible]~~, E. V., 1920, Milling plant of the Alaska-Gastineau Mining Co.: A. I. M. E., Trans., vol. 63, pp. 488-506.

16. Eakin, H. M., 1917, Lode mining in the Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 662-b, pp. 77-92.

17. Hall, R. G., 1938, Importance of flotation at the Alaska-Juneau mine: Eng. and Min. Jour., vol. 139, pp. 39-41.

18. Jackson, G. T., 1914, A concrete headframe (Perseverence): Min. and Sci. Press, vol. 109, pp. 99.

19. Jackson, G. T., 1919, Mining methods of Alaska-Gastineau Mining Co.: Am. Inst. Min. Bull., vol. 153, pp. 1547-1570.

20. Jackson, G. T., 1920, Mining methods of Alaska-Gastineau Mining Co.: A. I. M. E., Trans., vol. 63, pp. 464-487.

21. Kinzie, R. A., 1918, Alaska-Juneau: Min. and Sci. Press, pp. 183-185 and 322-324.

22. Knopf, Adolph, 1910, Mining in southeastern Alaska (1909): U. S. Geol. Survey Bull. 442-c, pp. 133-143.

23. Knopf, Adolph, 1911, Mining in southeastern Alaska (1910): U. S. Geol. Survey Bull. 480-d, pp. 94-102.

24. Parsons, F. W., 1917, Mining at Juneau: Eng. and Min. Jour., pp. 209-211.

25. Rickard, T. A., 1932, A history of American mining: McGraw-Hill Book Co., pp. 44-45, 57-81.

26. Spray, L. E., 1915, The Alaska-Gastineau mill: Min. and Sci. Press, vol. 110, pp. 612-614.

27. White, C. K., 1917, Alaska-Juneau 1520-foot raise: Eng. and Min. Jour., vol. 104, pp. 639-640.

28. Wright, C. W., 1917, Changes in Alaska-Juneau mill: Eng. and Min. Jour., vol. 106, pp. 352-359.

29. Wright, C. W., 1907, Lode mining in southeastern Alaska (1906): U. S. Geol. Survey Bull. 314-c, pp. 47-72.

30. Alaska-Juneau Gold Mining Company staff. The entire issue of the Eng. and Min. Jour., vol. 133, no. 9, 1932, was devoted to the Alaska-Juneau mine with articles as follows:

History, organization, and outlook, by P. R. Bradley, Consulting Engineer.
Development, mining, and transportation, by L. H. Metzgar, General Superintendent.
Milling methods and ore-treatment equipment, by W. P. Scott, Mill Superintendent.
Mechanical operations and rock disposal, by J. A. Williams, Chief Engineer.
Safety, welfare, and labor compensation, by L. H. Metzgar, General Superintendent.
Geology of the ore zones, by Livingston Wernecke, Consulting Geologist.
Surveying, sampling, and assaying, by J. A. Williams, Chief Engineer.
Purchasing methods and warehouse practice, By T. A. Hellenthal, Chief Accountant.

HISTORY

The following historical summary of mining of the Alaska-Juneau lode system was compiled from reports by Spencer (1906, pp. 2-3), Bradley (1932, pp. 460-461), and Rickard (1932, pp. 44-45, 57-81).

The history of mining of the Alaska-Juneau lode system is an integral part of the history of the whole Juneau area, including the Treadwell group of mines. In order to maintain the continuity of the following summary, references necessarily have had to be made to these other developments in the Juneau area, even though they do not directly pertain to the Alaska-Juneau lode system.

In 1879, the distinguished naturalist, John Muir, in company with S. Hall Young, was commissioned by the United State government to explore the coast line of southeastern Alaska from Windham Bay to Glacier Bay. His report (San Francisco Evening Bulletin, Jan. 10, 1880) prophesized that the area from Windham Bay to north of Berners Bay, now known as the Juneau Gold Belt, would prove to be rich in gold deposits. The later discoveries of fabulous mineral wealth near Juneau are testimony to the accuracy of Muir' s prophecy.

Muir's report was read by George E. Pilz of Sitka in 1880. Pilz, a mining engineer, had just completed the first 10-stamp mill at the Stewart claim on Silver Bay near Sitka. Two prospectors, Joseph Juneau, a French Canadian, and

Richard T. Harris, an American, were grubstaked by Pilz and Hall Bros. of San Francisco to prospect the mainland north from Windham Bay. According to a more generally heard report Harris and Juneau were grubstaked by N. A. Fuller of Sitka, but according to Brooks (formerly Chief of the Alaskan Branch of the U.S. Geological Survey, unpublished notes) who personally talked with Harris the prospecting agreement was as follows:

"In the year 1880 Richard T. Harris and Joseph Juneau entered into an agreement with George E. Pilz of Sitka and Hall Bros. of San Francisco to prospect the mainland of Alaska for gold and silver lode and placer mines. The agreement provided that Harris and Juneau as compensation for such service reserved the right to locate all gold placer they should find, while Pilz and Hall Bros in their turn should receive the first location on every quartz vein discovered by Harris and Juneau, who were to have the right to stake extensions of such quartz veins. In addition to the mining plans, Harris was to receive three dollars and Juneau two dollars for every day spent in prospecting. It is evident from the character of this agreement that the backers of the enterprise were seeking lode mines, rather than placers."

Harris had been a clerk in a store in Wrangell and later both he and Juneau had been employed in the Stewart mine. Juneau was a French-Canadian, a nephew of the founder of Milwaukee. Harris was placed in charge of the expedition, largely because Juneau was unable to read or write the English language. The expedition, consisting of Harris and Juneau and three Indians, left Sitka by canoe on July 19, 1880. They prospected Windham, Sumdum, and Snettisham bays, finding colors in some of the gravels but none in paying quantities. They continued north through Stephens Passage, passed between Admiralty and Douglas islands and arrived at Old Auk Village on August 13. From Auk Village they went as far north as Berners

Bay with discouraging results. On the 16th of August they returned and crossed the Mendenhall flats and camped at a stream which they named Salmon Creek. The next day Harris and Juneau discovered another stream from which they panned gold. They prospected this stream up to a point known as Snow Slide Gulch and found placer ground containing considerable gold. They then returned to the salt water with a small amount of placer gold and loose pieces of quartz containing free gold; they named the stream Gold Creek. By this time their provisions had been nearly exhausted so they returned to Sitka and reported to Pilz.

On September 29 they returned to Gold Creek and established a camp. A few days later they explored up Gold Creek in search of the loes from which the gold-bearing quartz had come. The water in Gold Creek was high at the time and they found it impossible to traverse the creek beyond what is now known as Cape Horn. They then climed Snow Slide Gulch and discovered Silver Bow Basin, the ground that is now the site of the Alaska-Juneau Mine. In Silver Bow Basin they found the outcrops of the gold-bearing quartz from which had been derived the quartz boulders they had found on their previous trip. In all about 1,000 pounds of ore were collected and sacked for shipment to Sitka. The next few days were spent in locating numerous placer and lode claims and in staking a townsite, which was called Harrisburg, at the mouth of Gold Creek. On November 18 they reported to

Pilz, who assayed the samples and reported them to carry $30,000,000 a ton. Needless to say, this report created a sensation and prospectors flocked to Gold Creek. On November 24 a steam launch from the U.S. Revenue cutter "Jamestown" took Harris, Juneau, and Pilz to the newly created town of Harrisburg. By 1881 upwards of 100 miners were at the new camp, and the Treadwell group of claims on Douglas Island had been staked as had most of the claims in the Gold Creek drainage. For a time the new camp was known as Harrisburg, but delay in mail delivery caused by the fact that much of the mail was missent to Harrisburg, Oregon, instead of Harrisburg, Alaska, necessitated a change in the name of the town. It was first called Pilzburg, then later Rockwell (after Lieutenant Rockwell of the Cutter "Jamestown"); finally at a meeting in December 1881 it was decided to rename the town Juneau, after the elder of the two discovers, and to name the district the "Harris mining district" after Richard T. Harris, at that time recorder of the district.

By 1882 both placer and lode mining were under way. Some of these old placer workings may still be seen on the slopes of Silver Bow Basin, particularly on the mountain sides above the Perseverance ground and above the glory hole of the south ore body of the Alaska-Juneau mine. Placer mining attracted the most attention, for it was the quickest and easiest way to secure immediate return for one's efforts. Placer mining in the Juneau area, though it produced over half a million dollars worth of dust, made but a minor contribution to the importance of this mining camp in its subsequent history. Lode mining, on the other hand, on which the future of the camp was to rest, attracted the attention of but a few far-sighted individuals. The placer deposits of Silver Bow Basin were first worked in 1891 by the Silver Bow Basin Mining Co. This same year ownership was acquired by the Nowell Gold Mining Co., who successfully worked the ground during the placer mining season from 1891 to 1902.

On the mainland side of Gastineau Channel mining during the period 1880 to 1900 did not proceed at the rapid pace that it did on Douglas Island. The history of mining on Douglas Island is a story in itself but does not belong in this report. The Ebner mine was worked by a man of that name who outlined the existance of seemingly large reserves of lode ore. The property was acquired by the United States Smelting and Refining Company in 1912 and an adit was started to undercut the ore at a depth of 1,200 feet. This project was discontinued in 1917 after the lode was undercut and explored with discouraging results. The Ebner mine remained idle until 1925 when the Alaska-Juneau Gold Mining Co. made an agreement with the U.S. Smelting and Refining Co. to mine Ebner ore, treat it in the Alaska-Juneau mill and pay the owner a royalty on a basis of the tonnage and grade mine from the Ebner.

The Perseverance mine first came into being in 1895 when Joseph T. Gilbert and partners acquired the property and built a 10-stamp mill. Mining was confined to surface outcrops. Operations ceased in 1899 when the surface installations were destroyed by a snowslide. In 1900 W. J. Sutherland (known as "Colonel" because of his having once been on the staff of a Cuban governor) took over the active management of the Perseverance mine and drove the Alexander Crosscut. Sutherland and Gilbert completed a 50-stamp mill in 1906 and added another bank of 50 stamps in 1907. Sutherland and Gilbert operated under the name of the Alaska Consolidated which was the holding company for the Perseverance Mining Co. The company produced ore regularly during the summer seasons until 1911 when Sutherland died. The heavy snowfall and severe weather prevented mining operations during the winter months. The mill was destroyed by fire in 1912. Prior to Sutherland's death Louis Shackleford brought the Perseverance Mining Co. into court by reason of claiming apex rights to the ground that Sutherland and his associates had mined. Shackleford, along with B. L. Thane of Juneau, and W. P. Hammon of San Francisco organized the Alaska-Gastineau Mining Co. for the purpose of acquiring the Perseverance property and consolidating it with the claims held by Shackleford and Thane. This was accomplished in 1912 and the company sent

D. C. Jackling and A. F. Holden to Juneau to examine the mine and to plan its development. Their plan was to construct a 6,000-ton mill at the mouth of Sheep Creek to undercut the Perseverance workings 700 feet below the old workings.

The plan was actively and vigorously purshed and by March 1915 the mill was receiving its first ore from the mine. A completely modern railway system and all the other adjuncts of a modern industrial plant were installed. A company town, known as Thane, was constructed on the Gastineau Channel 4 miles southeast of Juneau. To furnish power for such a large operation the company built three hydroelectric plants, two on Salmon Creek and one at Annex Creek on Taku Inlet. The large dam on Salmon Creek is of interest because it was among the first constant-angle, concrete-arch dams to be constructed. The successful completion of all of the development work within a period of three years was a notable achievement in mining history. At the onset the combined mining and milling costs were stated to be only 70 cents a ton, a most remarkable achievement.

The Alaska-Gastineau Mining Co. operated at a small profit during 1915-1917 but from 1918 to June 1921 when it ceased operations the company operated at a loss. The failure of the Alaska-Gastineau enterprise is attributed to several factors among which were an overly optinistic estimate of grade, uncontrolled dilution of the ore by caving from the upper stopes, mounting costs of operation brought about by the economic dislocation of the World War I, and finally the fact that the mill was designed for dry-crushing of ore whereas most of the ore delivered to the mill was quite moist. In this area the excessive rainfall permeated down through cracks in the rock caused by mining operations and the ore became wet.

Perseverance ground remained idle until 1933 when the neighboring Alaska-Juneau Gold Mining Co. purchased all of the Alaska-Gastineau Gold Mining Co. assets. At that time the entity of the Perseverance mine ceased; thereafter it was an integral part of the Alaska-Juneau mine, with the ore being developed from the adjoining Alaska-Juneau mine and the ore being treated in the Alaska-Juneau mill.

The Alaska-Juneau Gold Mining Co. was organized in 1897 and acquired 23 patented lode claims by purchase; these original claims have since proved to be the main part of the lode system on the mainland. In the year of its organization the company installed a 5-stamp mill to handle ore from selected open pits in Silver Bow Basin. This was augmented in 1896 by the addition of a 30-stamp mill. In 1903 underground operations were commenced from adits driven on the southwest slope of Silver Bow Basin. The early operators of the Alaska-Juneau recognized that gold values were contained only in quartz and they were the first to use sorting to increase the value of the mill heads.

In 1910 F. W. Bradley, who at the time was president of both the Alaska-Juneau Gold Mining Co. and the Treadwell groups of mines as well as consulting engineer for Treadwell, proposed that an adit be driven from an elevation of 420 feet on the slopes of Gastineau Channel to undercut the lode beneath the old workings in Silver Bow Basin. F. W. Bradley personally contracted with the Alaska-Juneau Gold Mining Co. to drive the adit and equip the mine and construct a pilot mill in return for one half of the company's stock. This entire development was completed late in 1913 and the mine and mill were successfully operated through 1916. It should be noted at this point that this pilot mill incorporated facilities for sorting of the ore prior to being milled, a feature that had been proved necessary from the early days.

In 1915 success seemed assured to the gigantic undertaking of the nearby Alaska-Gastineau Gold Mining Co. and many of Mr. Bradley's associates thought it advisable to undertake a similar large scale operation for the Alaska-Juneau mine. Mr. Bradley held out for a more modest operation, but because of failing health was forced to give up his side of the argument. The Board of Directors then authorized the issuance of stock for sale to the public in order to finance the construction of a 8,000-ton mill.

The mill was put into operation on April 1, 1917, and soon thereafter it became apparent that it was a failure. April 1917 was probably the most critical month in the history of Juneau. At the beginning of the month success seemed assured to both the Alaska-Juneau and the Alaska-Gastineau enterprises; the Treadwell mines across the channel were going at full capacity. By the end of the month all of the Treadwell group of mines, with the exception of the Ready Bullion, had caved and were flooded by sea water; the new mill of the Alaska-Juneau was a failure, and it was becoming increasingly apparent that the Alaska-Gastineau enterprise was encountering serious difficulties.

The 8,000-ton mill of the Alaska-Juneau had included no provision for prior sorting of the ore, and the crushing and grinding section of the mill did not function properly. The entire enterprise appeared doomed for failure; the company's funds were exhausted and it was deeply in debt. In the middle of 1917 F. W. Bradley, his health recovered, resumed control and an active program of mill redesign was carried on. A system of hand sorting was installed and the crushing and grinding section was completely revamped. Mr. Bradley personally advanced the major portion of the funds necessary for rehabilitation. The years 1920-1925, while the mill was being reconstructed, were trying and discouraging to the Alaska-Juneau Gold Mining Co. Finally, after courageous effort on the part of F. W. Bradley and his brother, P. R. Bradley, who served as resident manager from 1914 to 1920, and consulting engineer thereafter, the capacity of the mine was increased to slightly more than 10,000 tons per day, which after preliminary crushing and sorting were decreased to slightly more than half that amount to be put through the rest of the mill.

The history of the company's efforts is a brilliant story of engineering skill and in spite of seemingly insurmountable odds the company was finally able to solve all of the engineering problems and for the first time was able to declare a dividend in 1930. The success of the enterprise seems even more astonishing when it is noted that in 1930 the average yield per ton or ore was 90 cents and the average cost per ton of ore mined was about 50 cents.

In 1933 when the official price of gold was raised from $20.67 per ounce to $35.00 per ounce the Alaska-Juneau Gold Mining Co. entered into its most prosperous period of activity.

The controlling interests of the Alaska-Juneau and Treadwell group of mines had always been tied very close together and after the Treadwell group of mines ceased operations the Alaska-Juneau Gold Mining Co. assumed control of the former holdings of the Treadwell group of mines. In 1933 the Alaska-Juneau purchased the interests of the Alaska-Gastineau Gold Mining Co.

The most recent event in the long and colorful history of mining in the Juneau area was the shut-down of the Alaska-Juneau mine in April 1944. Early in World War II the high wages paid to workers on defense-construction jobs in Alaska and nearby Canada attracted many of the miners from Juneau and as a consequence the Alaska-Juneau was forced to reduce its output. Unit costs, therefore, increased and the company declared its last dividends in 1941. The management struggled to keep the mine open in the face of the labor shortage, but a War Labor Board decision that they must increase their wages forced the company to close the property. At present a small staff and maintenance crew is maintained in Juneau. The Alaska-Juneau mine, and the Treadwell group of mines before it, has long been the world's largest producer of low grade gold ore. The margin of profit per ton has been but a few cents and increased costs have naturally affected it more adversely than in the case with any other mines. It is expected that the Alaska-Juneau Gold Mining Co. will make every effort to protect its multi-million dollar investment at Juneau in anticipation of reopening when economic factors are more favorable than they are now.

PRODUCTION

Since 1914 the production records for the Alaska-Juneau lode system are quite reliable for all of the production was under the entire control of large companies that reported their annual production in their published annual reports. Prior to 1914 the record is uncertain. Smith (1942, pp. 182-183) has made what is considered to be the best estimate and his statement is as follows:

"Estimates as to the production of lode gold from the country immediately adjacent to and east of Juneau, here called the Juneau area, involve considerable uncertainty because of the various changes in ownership that have occurred whereby there has been duplication or overlap of some of the early reports and the distinction between lode and placer gold has not always been made. Thus Spencer, (1906, pp. 59-60), on extremely indefinite information, estimated that the mines in the Gold Creek area up to 1904 had probably produced about $2,250,000 in gold, of which about $1,000,000 was from lode mines. This estimate checks fairly closely with certain records from other sources. For instance, Spencer states that the Ebner mine on Gold Creek had produced gold to the value of $575,000 up to the end of 1902, and in 1903 had produced lode gold worth in excess of $25,000, or a total of $600,000. In its annual reports the Alaska-Juneau, which has operated the only other large lode-gold property in Gold Creek, combines all of its production from 1893 to 1913, inclusive, in one item, which is given as $707,730 (see page 27). If from this total is subtracted the amount recorded in the reports available in the Geological Survey for each of the years 1906 to 1913, it is found that the remainder, representing the production from 1893 to 1905, inclusive, is $510,079. However, some doubt is felt as to just what area is included in this company's early record, because the company was not organized until 1897, so that the earlier records of production for the claims it later acquired were assembled from various sources, which are no longer available for analysis. Unless it includes more than the production from its own restricted holdings, the amount seems excessive, because up to 1896 only a small 5-stamp mill was in operation on its property, and the mill was running only during the summer months. In 1896 a 30-stamp mill was built, which also was run only during the summer.***"

"***It is believed, therefore, that something like $200,000 now attributed to the Alaska Juneau property, came from other properties.***"

For this report the entire sum reported by the Alaska-Juneau Gold Mining Co. for the years 1893 to 1913, inclusive, is given as reported by that company. The production of the Alaska-Juneau mine, as reported by the Alaska-Juneau Gold Mining Co., is given in table 2 and shown in graphical form on figure 1.

Table 1 gives the production of the Perseverance mine. Data for the years 1907 to 1912, inclusive, and for the year 1921 are from Smith (1942, table 5, pp. 186-187) and are only the value of the gold produced and do not include small supplemental values obtained from contained silver, zinc, and lead. Data for the years 1915 to 1921, inclusive, are from annual reports of the Alaska-Gastineau Gold Mining Co. In 1934 the entire holdings of the Alaska-Gastineau were purchased by the Alaska-Juneau Gold Mining Co. and all subsequent yield from the Perseverance mine is included in the production of the Alaska-Juneau mine.

Table 1, Production of the Perseverance mine

Year	Tons crushed	Yield per ton	Total yield
1907	?	?	$ 65,122 (1)
1908	?	?	160,000 (1)
1909	?	?	121,055 (1)
1910	?	?	119,189 (1)
1911	?	?	97,743 (1)
1912	?	?	73,465 (1)
1913	none	none	none
1914	none	none	none
1915	1,115,294	$0.94	1,046,104
1916	1,892,788	0.97	1,837,291
1917	2,240,348	0.90	2,009,632
1918	1,285,445	0.88	1,136,223
1919	2,251,658	0.66	1,474,491
1920	2,133,458	0.70	1,487,576
1921	?	?	725,952 (1)
		Total	$10,353,843 (2)

(1) Gold values only, does not include lesser amounts of silver, lead, and zinc.
(2) Does not include an unknown amount of production for the years 1895-1907. Production from 1934 to 1944 is included as part of the Alaska-Juneau mine.

TABLE 2, PRODUCTION OF ALASKA-JUNEAU MINE

Year	Tons trammed	Tons milled	Yield per ton trammed	Yield per ton milled
1893-1913	507,254	330,278	$1.40	$2.14
1914	62,436	60,026	0.94	[illegible]
1915	179,892	179,892	1.19	1.19
1916	180,113	180,113	0.61	0.61
1917	677,410	677,410	0.68	0.68
1918	592,218	574,285	0.78	0.80
1919	692,895	616,302	0.78	0.88
1920	942,870	637,321	0.84	1.24
1921	1,613,600	904,323	0.64	1.15
1922	2,310,550	1,108,559	0.60	1.25
1923	2,476,240	1,134,759	0.61	1.33
1924	3,068,190	1,367,528	0.67	1.50
1925	3,481,780	1,537,884	0.63	1.44
1926	3,829,700	1,649,678	0.54	1.25
1927	4,267,810	1,839,695	0.58	1.33
1928	3,718,140	1,795,191	0.89	1.84
1929	3,836,440	2,020,470	0.95	1.79
1930	3,924,460	2,066,239	0.90	1.72
1931	4,162,350	2,298,998	0.93	1.69
1932	4,001,630	2,414,469	0.81	1.33
1933	4,085,960	2,466,832	0.97	1.61
1934	4,302,600	2,387,138	1.06	1.92
1935	3,729,660	2,091,475	1.15	2.05
1936	4,366,800	2,462,046	1.24	2.20
1937	4,442,760	2,251,079	1.24	2.45
1938	4,663,880	2,478,928	1.15	2.16
1939	4,648,060	2,377,718	1.01	1.98
1940	4,739,790	2,308,397	0.94	1.93
1941	4,354,770	2,211,211	1.00	1.98
1942	2,765,190	1,624,601	0.99	1.69
1943	1,461,830	898,384	1.00	1.62
1944	378,800	240,879	0.93	1.47
1945	none	none		
1946	none	none		

(1) From Plant absorption cleanup

Summary

Tons trammed.....................88,466,078
Tons milled......................47,192,108
Average yield per ton trammed.........$0.91
Average yield per ton milled..........$1.72
Total yield......................$81,020,841
Ounces of gold....................2,888,996
Ounces of silver..................1,949,819
Pounds of lead...................40,219,231

Yield per ton milled	Total yield	Metals Recovered: gold (ounces)	silver (ounces)	lead (pounds)
$2.14	$ 707,730	34,240	not recovered	
0.98	58,691			
1.19	214,878	38,507	21,284	474,278
0.61	110,443			
0.68	459,360			
0.80	459,446	20,809	11,828	273,297
0.88	542,714	24,141	16,431	359,762
1.24	791,390	35,456	23,348	487,574
1.15	1,035,251	46,914	40,619	550,913
1.25	1,388,679	62,707	49,405	687,315
1.33	1,514,774	69,047	41,876	755,423
1.50	2,055,782	92,277	63,191	1,256,857
1.44	2,184,384	98,213	55,971	1,[illegible]3,974
1.25	2,067,837	93,423	52,333	1,300,915
1.33	2,463,262	112,653	61,232	1,513,306
1.84	3,318,019	152,047	77,591	2,038,655
1.79	3,627,247	164,993	90,635	2,501,832
1.72	3,551,950	163,312	97,607	2,640,771
1.69	3,875,839	179,532	118,508	3,300,176
1.33	3,236,183	151,578	94,519	2,509,263
1.61	3,960,165	150,967	10?,483	2,290,777
1.92	4,582,559	128,015	86,458	1,662,804
2.05	4,231,110	118,936	77,787	1,455,167
2.20	5,400,621	149,235	101,591	2,102,504
2.45	5,716,414	151,671	120,691	1,900,405
2.16	5,[illegible]54,498	148,103	121,473	2,152,714
1.98	[illegible],537	129,012	111,404	2,[illegible]40,280
1.93	4,[illegible]47,171	122,470	100,633	1,666,016
1.98	4,370,920	120,601	95,777	1,464,956
1.69	2,749,118	75,537	62,298	938,117
1.62	1,455,861	39,927	35,531	400,000
1.47	353,518	9,712	8,454	88,000
	119,048 (1)	3,333	1,508	30,000
	56,452 (1)	1,665	263	none

78
08
01
72
41
06
19
31

The total value of the estimated production of the Alaska-Juneau lode system is given below:

1.	Lode production of Alaska-Juneau mine 1893-1946	$81,020,078
2.	Lode production of Perseverance mine 1907-1921	10,363,843
3.	Lode production of Ebner mine (excludes values obtained during lease to Alaska-Juneau).	600,000
4.	Lode production of other small properties on Gold Creek.	400,000 (1)
5.	Placer production from Gold Creek.	1,308,000
	Total	$93,682,681

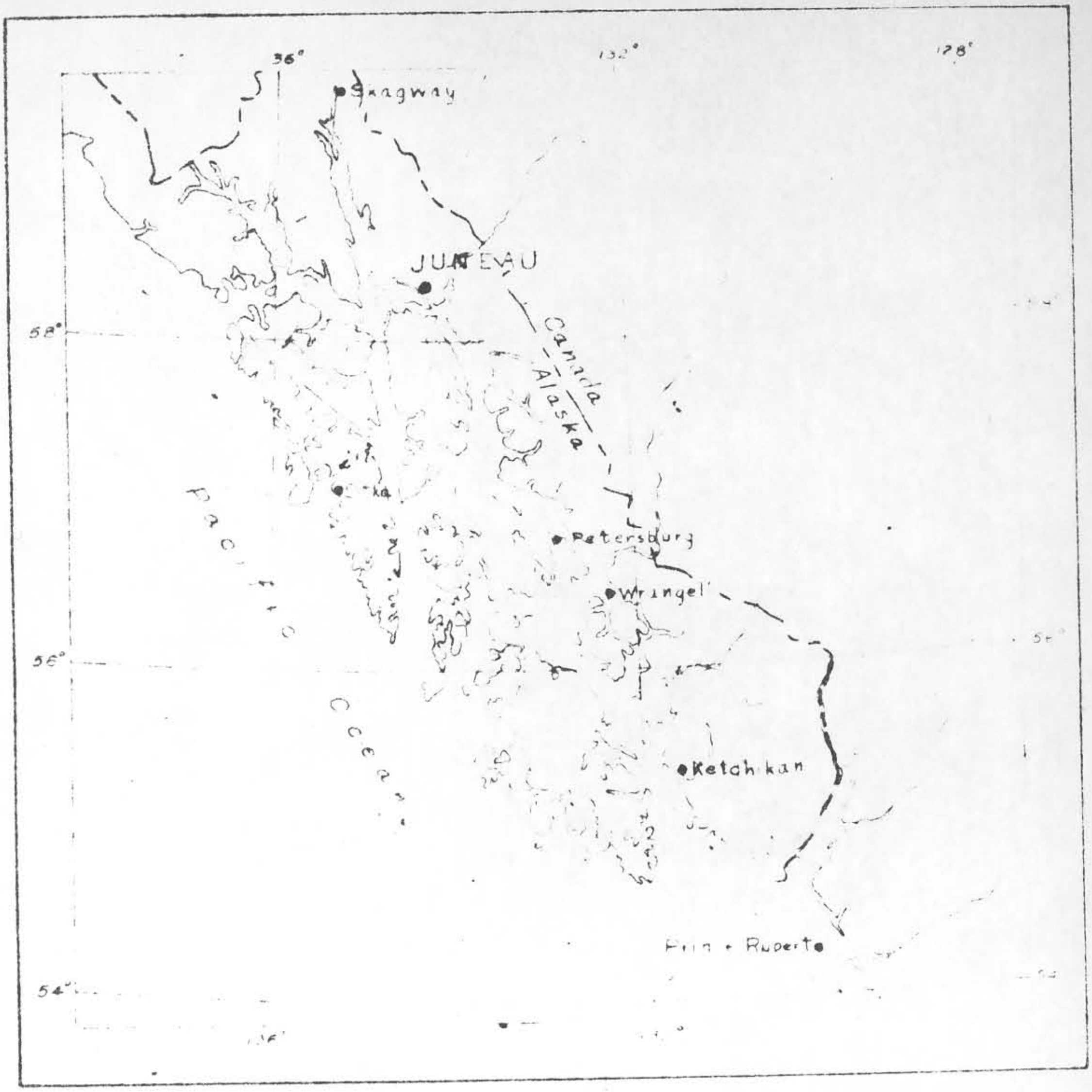
(1) Probably includes production from Perseverance for period 1895-1907.

LOCATION, CULTURE, AND ACCESSIBILITY

The Alaska-Juneau lode system is on the mainland of southeastern Alaska about 3 and one-half miles northeast of the city of Juneau. Juneau is a modern city of about 8,000 people and is the capital of the Territory as well as the main Alaskan headquarters of many Federal agencies. It is situated at the delta of Gold Creek and on the surrounding slopes of Mt. Juneau and Mt. Roberts. It is separated from the town of Douglas and Douglas Island by Gastineau Channel, a northwest-southeast trending fiord.

Juneau is served at least once a week from Seattle by the Alaska Steamship Co. with interconnections to nearly all of the other Alaskan ports. Canadian Pacific Steamship Co. and Canadian National Steamship Co. serve Juneau from Vancouver, B. C. during the summer months. The harbor is well protected and is suitable for ships of any size. Daily

FIGURE 1



INDEX MAP OF SOUTHEASTERN ALASKA

plane service is maintained with Seattle by Pan American World Airlines, and with Anchorage by Pacific Northern Airlines. Daily plane service is maintained to all towns of southeastern Alaska by Alaska Coastal Airlines and Ellis Airlines. There are no road or railroad connections from Juneau to the "Outside". During summer months a ferry service is operated between Juneau and Haines with connections to the Alaska Highway.

Throughout most of its history the principal industry in Juneau has been gold mining. Ever since 1912 when the capital of the Territory was changed from Sitka to Juneau there has been a steadily increasing proportion of the population employed by the Territorial and Federal governments. The fishing and timber industries contribute a small but substantial income to certain Juneauites. For many years the gold-mining industry employed upwards of a thousand persons. The number of persons employed in the mining industry began to decrease in 1940 as the lure of higher wages paid for war-time construction elsewhere in Alaska and Canada attracted workers away from Juneau. Since 1944 when mining ceased in the vicinity of Juneau the principal source of outside income for Juneau has been its government payroll. Fortunately for Juneau the government payroll increased as the mining-industry payroll decreased and as a consequence the economy of Juneau has changed but little.

Roads from Juneau extend across Gastineau Channel to Douglas Island and thence to the town of Douglas, to Thane, a community of less than a dozen families about 4 miles southeast of Juneau and, to Auk Bay and Eagle River northwest of town. Many persons maintain summer and year-round homes near Auk Bay.

Juneau and vicinity produces very little of its own foodstuffs; virtually all of it is imported from Seattle sources.

The cost-of-living in Alaska is considerably higher than in the States. Prices for more services and commodities are about 25 per cent higher in southeastern Alaska and 40 to 50 per cent higher elsewhere in Alaska than prices in the States. Wage scales are comparably higher than Stateside wages.

PHYSICAL FEATURES

The Alaska-Juneau lode system lies on the southwest flank of the Coast Range of southeastern Alaska. Southeastern Alaska is an area of rugged and mountainous relief with thousands of mountainous islands and interconnecting waterways. Altitudes range from sea level to peaks on the British Columbia-Alaska boundary on the crest of the Coast range that attain heights of 10,000 feet. The mountain slopes are generally very steep, the valleys are narrow and areas of low flat land exceeding a few square miles are very rare.

The Glaciers and fiords of southeastern Alaska are among the most magnificent in the world. Several score of glaciers extend to tide water and in the higher mountains are thousands of smaller glaciers. The mountains, fiords, glaciers, and forests of southeastern Alaska constitute a most valuable scenic asset that is as yet only partially developed and publicized as a tourist attraction.

Buddington's and Chapin's (1929, p. 23) description of the topography of southeastern Alaska is as follows:

"***at many places cliffs rise sheer from the water's edge to altitute of 2,000 to 5,000 feet; and a short distance back from the shore snowy peaks 6,000 to 7,000 feet high are common. *** Thousands of small glaciers occur in the mountains, some clinging to slopes so steep as to cause wonder how they can remain there, and some terminating in ice cliffs from which huge masses are continually falling. Some of these valley glaciers discharge icebergs into the sea. Here and there waterfalls, starting hundreds or thousands of feet high on the mountain sides, plunge down in a series of cascades into the valleys or into the sea. So steep are many of the mountain slopes that great landslides are common, and long triangular scars, both old and recent, are a feature of many views.***"

"The topography is that of an adolescent rugged mountainous region, in which the ranges have been deeply dissected by river erosion, modified by the great Pleistocene ice sheet, and sculptured by alpine glaciers of Pleistocene and Recent age.***"

"The evidences of the great ice flood of Pleistocene time are found in the fiorded coast line, in the modified shape of most of the pre-existing river valleys, in the presence of hanging valleys, in polished, grooved, and striated surface, and in roches moutonnees. The results of extensive alpine glaciation are seen in the many cirques, tarns or mountain lakes in rock-rimmed basins, knife-edged or comb ridges between cirques, and Matterhorn-like peaks, on both the mainland and the larger islands of the archipelago."

The topography and physical features of the country in the vicinity of the Alaska-Juneau lode system are shown on the U.S. Geological Survey quadrangle sheet entitled, "Juneau and vicinity, Alaska."

The Alaska-Juneau lode system is a northwest-southeast trending structure that extends southeast almost to the crest of the ridge between Sheep Mtn. and Mt.

Roberts, and extends northwesterly across Icy Gulch and along the southwest flank of Gold Creek valley for about two miles, and thence across Gold Creek valley for about two miles, and thence across Gold Creek and part way up the southeast flank of Mt. Juneau. The principal production has been obtained from the central part of the lode system.

The most prominent mountains are Mt. Juneau (3576 feet), Mt. Roberts (3810 feet), both on the mainland, and Mt. Bradley (3337 feet) on Douglas Island.

On the mainland side of Gastineau Channel the mountain slopes rise abruptly from the water's edge; the slopes are interrupted by several streams rising 5 or 6 miles back from Gastineau Channel. These are Sheep, Gold, and Salmon Creeks.

The land on the Douglas Island side of Gastineau Channel rises gradually from the sea to altitudes of from 400 to 600 feet about a mile from the coast, and then the slopes abruptly increase to a steep rise to the ridge and mountain tops. The mountain slopes are dissected by the Nevada, Ready Bullion, Bullion, Paris, Lawson, and Cowee creeks.

Gastineau Channel bears unmistakable evidence, in its U-shaped cross section and the truncated mountain spurs, of former glaciation. All of the present stream valleys also were glaciated in recent times. They are typically U-shaped with over-steepened valley walls. All of the streams have their

headgate

headwaters in well-formed cirques.

All of the present land surface in the Juneau area was glaciated. The land surface above about 2,500 feet altitude in the Gastineau Channel drainage was glaciated long prior to the most recent valley glaciation.

WATER POWER

The Alaska-Juneau Gold Mining Co. owns all of the power plants in the Juneau area, with the exception of one small hydroelectric plant owned by the Alaska Electric Light and Power Co. distributors of electric power for the City of Juneau. The power plants serving the Juneau area are listed below:

Plant	Average horsepower*
Annex Creek	4,530
Treadwell	1,020
Sheep Creek	2,090
Nugget Creek	2,320
Upper Salmon Creek	3,020
Lower Salmon Creek	2,470
Alaska-Juneau steam plant	5,965
Gold Creek	700
	22,115

*Figures from "Water power of southeast Alaska," report by Federal Power Commission and the U.S. Forest Service, 1947.

The Annex Creek power plant is on the shore of Taku Inlet 21 miles by water from Juneau and is interconnected with the Juneau system by a 15 mile overland transmission line. Runoff is regulated by a 10-foot timber dam and a tunnel 154 feet below dam level. The mean effective head is 755 feet. The power installation was started in 1915 by the Alaska-Gastineau Gold Mining Co. and completed in January 1916. Title to the power installation was acquired by the Alaska-Juneau Gold Mining Co. in 1934 when it purchased all the assets of the Alaska-Gastineau Gold Mining Co.

The Treadwell power plant is located about a mile south of the town of Douglas on Douglas Island. Water is supplied from the 14-mile long Treadwell Ditch which collects water from Fish, Eagle, Cowee, Lawson, Paris, Bullion and Ready Bullion creeks and brings it to the power plant. The effective head is about 500 feet. The Treadwell Ditch is now in disrepair and no attempt is made to keep it in repair. There are no provisions for water storage. The original installation was started in 1882 by the Alaska-Treadwell Gold Mining Co. and operated by them until 1928 when all the assets of the company were acquired by the Alaska-Juneau Gold Mining Co.

The Sheep Creek power plant is at the mouth of Sheep Creek 4 miles southeast of Juneau. Water is diverted from Sheep Creek at the 620-foot altitude into a flume and thence into a steel penstock to the power house at sea level. There are no provisions for water storage. The effective head is 600 feet. The original installation was started in 1910 by the Orford Mining Co. and was replaced by a larger installation built in 1914 by the Alaska-Treadwell Gold Mining Co.

The plant was acquired by the Alaska-Juneau Gold Mining Co. in 1928 when it when it acquired all the assets of the Alaska-Treadwell Gold Mining Co.

The Nugget Creek power plant is near the front of Mendenhall Glacier 14 miles northwest of Juneau. Water is diverted from Nugget Creek, just before it flows under Mendenhall Glacier, into a rock tunnel and thence into a wooden stave conduit to a point on the mountain slope 490 feet higher than the power house. The original installation was constructed in 1913 and 1914 by the Alaska-Treadwell Gold Mining Co., the Alaska-Mexican Gold Mining Co., and the Alaska-Gold Mining Co. The Alaska-Juneau Gold Mining Co. acquired the property in 1928 when it purchased all the assets of the Alaska-Treadwell Gold Mining Co.

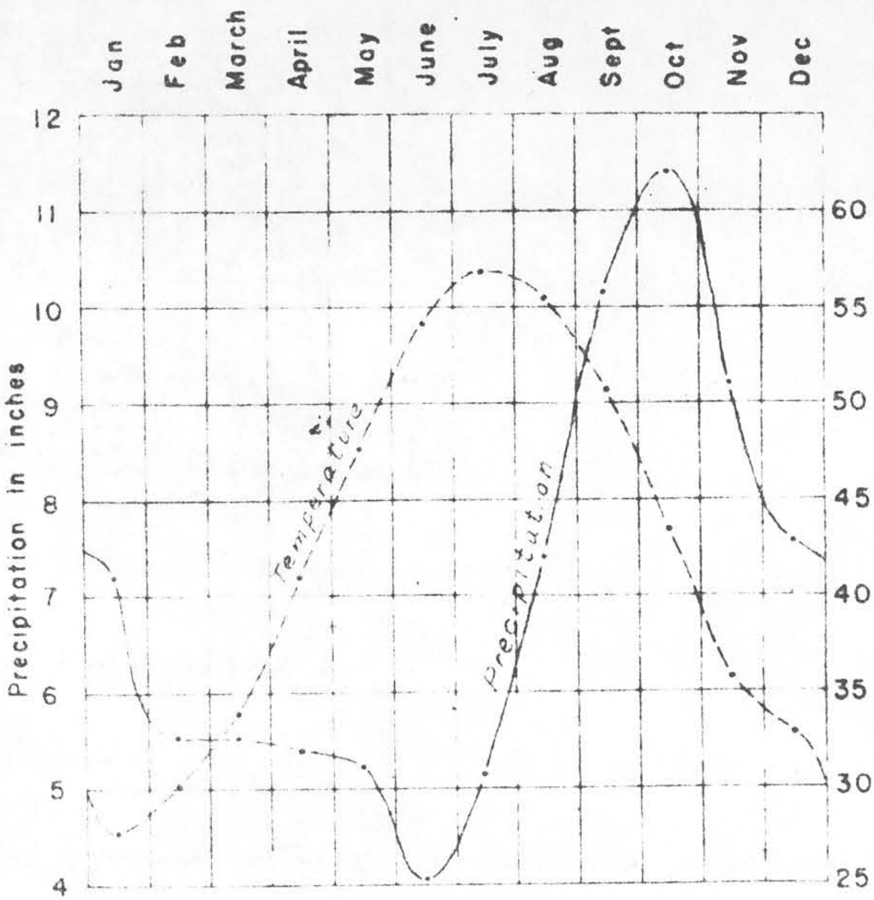
The Upper Salmon Creek power plant is located at 467-foot altitude 2 miles from the mouth of Salmon Creek. The lower Salmon Creek power plant is at tide-water 2 and one-half miles northwest of Juneau. Water storage and regulation is accomplished by means of a 170-foot high dam, whose crest is at 1,177-foot altitude. Water from the reservoir is conducted by means of a steel pipe to the upper Salmon Creek power plant. The mean effective head is 583 feet. Water from the tailrace of this power plant is conducted in a flume along the south slope of Salmon Creek to a steel penstock which carries the water to the lower Salmon Creek power plant. The effective head of this installation is 388 feet. Both of the power plants and the concrete dam were constructed in 1915 by the Alaska-Gastineau Gold Mining Co. Ownership passed to the Alaska-Juneau Gold Mining Co. when it purchased the Alaska-Gastineau Gold Mining Co. in 1934.

The Alaska-Juneau steam plant was constructed in 1917 near the offices and warehouses of the Alaska-Juneau Gold Mining Co. just southeast of the city limits of Juneau. It was originally intended to supply electric power to the Alaska-Juneau operation, because at that time the Alaska-Gastineau and the Treadwell group of mines required all of the hydroelectric power then available. After the closing of theAlaska-Gastineau and Treadwell operations the steam plant was needed only for standby use when water supplies became low in winter months, or when transmission lines were broken.

The power plant of the Alaska Electric Light and Power Co. is in the City of Juneau and obtains its water from Gold Creek. Water is diverted from Gold Creek at 240-foot altitude into a flume and thence into a steel penstock leading to the power house. The effective head is 220 feet. This plant is not capable of supplying all the needed electrical energy for the City of Juneau, and the remainder of the needed power is supplied by purchase from the Alaska-Juneau Gold Mining Co.

All of the power plants, with the exception of the Nugget Creek plant which has not operated for several years, are interconnected through a central station

FIGURE 2



AVERAGE MONTHLY TEMPERATURE AND PRECIPITATION, JUNEAU, ALASKA at the Alaska-Juneau steam plant in Juneau. The two plants with provision for storage, namely Annex and Salmon creeks, are used only when the stream-flow plants cannot supply the requirements of the City of Juneau. Ever since the Alaska-Juneau mine closed in 1944 there has been an excess of electric energy available.

CLIMATE

The average monthly precipitation and temperature at Juneau is given on the accompanying graph. (Data from, Climatological Data: 1949, vol. 35, no. 13, U.S. Depart. of Comm., Weather Bureau). The average total yearly precipitation for Juneau is 83.7 inches, most of which falls as rain. The average snowfall for Juneau is about 9 feet. June is the driest month (average 4.04 inches) and September and October are the wettest months (average 10.17 and 11.41 inches, respectively).

The mean annual temperature is about 42°F. The highest temperature ever recorded is 89°F. and the lowest minus 15°F. The coldest month is January with an average temperature of 27.8°F. and the warmest is July with an average of 56.7°F. The moderating influence of the Pacific Ocean and the Japanese Current is seen in the above figures.

Sunshine at Juneau average 29 per cent of the total possible amount.

The prevailing winds from the southeast are warm and moist and generally bring cloudy and rainy weather. Extremely strong and gusty northerly winds, locally know as "Taku Winds" are frequent during winter months and are invariably accompanied by clear and cold weather.

The Juneau harbor is open year-round. During periods of cold the harbor will freeze with a few inches of surface ice, but generally the movement of the tides rapidly breaks the ice and it is dispersed.

Precipitation apparently is markedly increased at higher altitude. During the years 1916-1937, a total of 90 months of record were obtained at the Perseverance camp in Silver Bow Basin of Gold Creek. The records indicate that the Perseverance campt at altitude 1,400 feet receives an average of 176 per cent of the precipitation recorded at Juneau only three miles away (Federal Power Commission and U.S. Forest Service, 1947, pp. 16-17.) Other weather stations in southeastern Alaska indicate a similar increased rainfall at higher altitudes.

As in most regions, temperatures are lower the higher the altitude.

VEGETATION

The Juneau area, like most of southeastern Alaska, has vegetation characteristic of the typical temperate-zone, rain-forest of coast regions. The forest cover might best be described as jungle-like, consisting as it does of dense stands of spruce and hemlock with an even more dense undergrowth of small bushes and shrubs. Muskegs are common on flat uplands and on poorly drained steep slopes. Small dwarfed lodgepole pines grow only on the muskeg areas. The undergrowth consists of devil's club, willow, alder and small berry bushes such as salmonberry and blueberry.

Timberline generally lies at between 1,500 to 2,000 feet above sea level. For a short distance above timberline is a dense growth of alder and salmonberry bushes, and then upwards the slopes are bare or covered with grasses and flowers.

The dense vegetation below timberline renders travel by foot extremely difficult and prospecting virtually fruitless. By necessity geologic mapping and examination are confined to the almost perfect shoreline exposures, the creek bottoms, and the ridge tops.

DESCRIPTIVE GEOLOGY

GENERAL FEATURES

The rocks in the vicinity of the Alaska-Juneau lode system consist of an extremely thick sequence of clastic sediments and volcanics intruded by the Coast Range batholith, and related satellite intrusives, with consequent metamorphism and tilting of all rocks older than the batholith. Fossils have been found at only one place within the Juneau area (Gastineau volcanic group) and all age assignments are problematic. Age determinations by lithologic correlation with nearby localities have not been satisfactory.

Listed below, in approximate order of age from youngest to oldest, are the various rock units that have been recognized and mapped in the Juneau area:

Table 3, Stratigraphic Section for the Juneau area

No.	Rock unit	Thickness (feet)	Lithology and remarks	Age
9	Alluvium, beach deposits and moraine.	?	Stream, marine, and glacial silts, sands, and gravels, all unconsolidated.	Pleistocene and Recent.
8	Unconformity			
7	Alaskite, basalt dikes and sills.	1-20	Uniform and persistant dikes, generally steeply dipping, unmetamorphosed.	Tertiary (?)
6	Coast Range intrusives.			
6a	Coast Range batholith.	?	Coarse-grained quartz diorite and granodiorite plutonic intrusives.	Jurassic or Cretaceous.
6b	Hornblendite sill.	100-200	Coarse-grained hornblendite found only within Treadwell slate.	Jurassic or Cretaceous.
6c	Meta-gabbro sills.	200-300	Amphibole schists and amphibolites formed from metamorphism of gabbro sills ~ flows? found only with Perseverance slate. Spatially associated with ore bodies of Alaska Juneau lode system.	Jurassic or Cretaceous
6d	Albite-mica schist.	200-1,000	Medium- to coarse-grained Mafa. → sills found only within Perseverance slate.	Jurassic or Cretaceous.
6e	Diorite porphyry sills. oligo plено Hbde.	200-300	Medium-grained, porphyritic diorite found only as sills within Treadwell slate.	Jurassic or Cretaceous.

Table 3, (Cont.)

No.	Rock unit	Thickness (feet)	Lithology and remarks	Age
5	Clark Peak schist.	10,000-15,000	Quartzose and feldspathic schist and gneiss metamorphosed from clastic sediments. Interfingers with Perseverance slate.	Mesozoic (?) post-Upper Triassic (?)
4	Perseverance slate.	2,000-3,000	Black slate, black phyllite, and thinly-bedded quartzite. Conformably overlies Gastineau volcanic group.	Mesozoic (?) post-Upper Triassic (?)
3	Gastineau volcanic group	6,000-7,000	Chlorite and amphibole schist metamorphosed from andesite and basalt lava flows and tuffs. Includes some chlorite phyllite and black slate.	Mesozoic Upper Triassic
2	Treadwell slate	4,000-15,000	Black slate and black phyllite with increased amounts of graywacke to the northwest of Juneau. Interfingers with Douglas Island volcanic group.	Mesozoic (?) pre-Upper Triassic (?)
1	Douglas Island volcanic group	5,000-10,000	Basalt flows, tuffs, agglomerates, with breccias. Interfinger with Treadwell slate.	Mesozoic (?) pre-Upper Triassic (?)

With the exception of the Tertiary (?) dikes and Pleistocene and Recent sediments, all of the rock units strike approximately northwest-southeast and dip from 20 to 85 degrees, (average about 55 degrees), to the northeast. The regional structure is thus a monocline. On the northeast the bedded rocks are intruded and bounded by the Coast Range batholith whose contact with the bedded rocks approximately parallels the structure of the bedded rocks. In detail the contact appears to parallel the bedding; however, along the strike of the contact to the northwest the batholith progressively cuts across successively older rocks and is truly a transgressive contact. The Coast Range batholith has linear and planer elements which parallel those of the bedded rocks.

No folds larger than a few tens of feet in wave-length are known to exist, and these are confined to the Treadwell and Perseverance slates, which, it seems, were less competent than the other rocks and yielded to orogenic stresses by small-scale, drag-folding.

There are hundreds, if not thousands, of faults cutting the bedded rocks; because of the difficulty of recognizing faults beneath the surface cover of vegetation, only a few of them have been mapped on the surface. The most prominent is Silver Bow fault, a steeply dipping, east-west cross fault that cuts across the Alaska-Juneau lode system. Hundreds of faults subsidiary to Silvery Bow fault have been recognized and mapped underground.

The surface features of the Juneau area are the result of stream and river erosion followed by alpine glaciation and changes in sea level with respect to the land. As in most glaciated areas the glaciers have so modified the landforms that the bed-rock geology finds little expression in the present land surface, except for minor features such as gullies formed since glaciation along fault zones or other zones of weal rock. The characteristic land forms are U-shaped valleys, fiords, over-steepened mountain slopes, rounded mountain tops and valley bottoms partially filled and covered with glacial deposits.

The two principal lode systems in the Juneau area are the Alaska-Juneau lode system, and the Treadwell lode system. The latter is not described in detail in this report; the ore bodies consist of mineralized portions of the Treadwell Dike, one of the diorite porphyry sills within the Treadwell slate. Gold was by far the most valuable mineral in the Treadwell deposits.

The Alaska-Juneau lode system is confined to the Perseverance slate. The deposits, which are chiefly valuable for gold but also contain small amounts of silver and lead, consist of stockworks of quartz veins near slate and metagabbro contacts. Values are confined almost entirely to the veins themselves, a situation that makes hand sorting of the ore feasible.

DOUGLAS ISLAND VOLCANIC GROUP

Distribution and Character

The Douglas Island volcanic group of rocks form the backbone of Douglas Island and extend the length of the island. These rocks can be traced northwesterly from Douglas Island along the east shore of Favorite Channel and Lynn Canal to Berners Bay, and southeasterly along the Glass Peninsula of Admiralty Island. The Douglas Island volcanic group is included in the "slate-greenstone band" described by Spencer (1906, pp. 16-18, pls. 4 and 37) and represented on his geologic map. Wright (1906, pp. 141-142, pl. 33) described a belt of "slates and greenstones" that occur throughout Glass Peninsula on Admiralty Island; the greenstones presumably are the southeasterly continuation of the Douglas Island volcanic group. The volcanic rocks mapped and described by Knoph (1912, pp. 18-20) as augite melaphyres are the northwesterly continuation of the Douglas Island volcanic group.

The Douglas Island volcanic group of rocks prevailingly strike about N. 45° W. and dip from 20 degrees to 75 degrees to the northeast. Local variations from the prevailing altitude are found, but such variations are few and of minor consequence. On the northeast the volcanic rocks are bounded by the Treadwell slate and on the southwest are bounded by an unnamed sequence of rocks comprised of slate, graywake, and conglomerate. This latter sequence of rocks crops out on the west side of Douglas Island and on Portland, Coghlin, and Shelter Islands. All evidence indicates that the Douglas Island volcanic group is conformable with both the overlying Treadwell slate and the unnamed underlying sedimentary sequence. The boundary drawn between the Treadwell slate and the Douglas Island volcanic group is quite arbitrary. As one crosses the boundary from northeast to southwest, a few isolated narrow bands of volcanic rocks are first encountered interbedded with the Treadwell slate. As one continues southwest the volcanic bands become more and more numerous until finally the slates are entirely missing and the volcanic rocks make up the bed rock. However, well within the predominantly volcanic section are found occasional narrow bands of slate. Although the southwest boundary of Douglas Island volcanics is outside the area covered by this report, a brief study has indicated that the boundary between the volcanics and the unnamed slate-graywacke-conglomerate sequence similarly is transitional. The structure of the sedimentary rocks on either side of the volcanic rocks is identical with that of the volcanic rocks and no evidence was found of an unconformity.

Within the area covered by this report the total stratigraphic thickness of the volcanics is nowhere exposed. However, elsewhere these rocks range in thickness from a few hundred feet on the north side of Douglas Island to over 10,000 feet near the center of Douglas Island. The volcanics range in size from narrow sheets to enormous thicknesses of several thousands of feet.

The dominant rock type is volcanic breccia; in fact, it is doubtful if within the whole belt of the Douglas Island volcanic group there is any band of rock more than ten feet in thickness that does not contain some volcanic breccia. The breccia fragments range in size from blocks three or four feet in diameter down to pieces one-quarter inch or less across. The fragments as a rule are quite angular although at places they are so rounded as to be properly classed as conglomerates. Fragments range from particles of approximately equidimensional size to elongated and lens-shaped fragments. At many places the unequidimensional fragments are somewhat preferentially oriented to give a crude planar structure to the rock. This planar structure is parallel to the general trend of the rocks of this region, namely, striking northwest-southeast and dipping steeply northeast. The fragments on the average comprise at least 80 per cent of the mass of the rock. The matrix is the same material as the fragments and on a fresh surface it is virtually impossible to distinguish the fragmental character of the rock. However, on weathered surfaces, particularly where the rocks are exposed along the sea coast, the brecciated character of the rock is most apparent.

The Douglas Island volcanic rocks are thoroughly indurated and are among the most resistant rocks in the region. They are massive and well jointed and individual flows can be determined only where bounded on both sides by sedimentary rocks. Dynamic metamorphism which has so prominantly affected the rocks on either side of the volcanic belt has but little affected the volcanic breccias. They show little schistose structure except for the crude planar arrangment of the breccia fragments.

Lithology

Shades of green and brown are the dominant color of the Douglas Island Volcanic rocks. Because of the green color both Spencer (1906,pp. 16-18) and Wright (1906, pp. 141-142) called these volcanic rocks greenstones, but the author prefers the term augite melaphyre originally proposed by Knopf (1912, pp. 19-20). The term greenstone is a term loosely used in geologic literature to describe any altered volcanic rock and the term is better applied in the Juneau area to the Gastineau and Thane sequence of rocks. Actually the Douglas Island volcanic rocks are but slightly altered in comparison with the other rocks of the Juneau area.

Knopf (1912, pp. 19-20) described the northwestern continuation, north of Auke Bay, of the Douglas Island volcanics as follows:

"The characteristic feature of all these rocks***is their unfailing content of augite. In the massive varieties augite forms numerous well-preserved phenocrysts of sharply idiomorphic development and of dark vitreous brown green color. Porphyritic feldspars are notably absent. At some localities the augite phenocrysts make up half of the bulk of the rock. Microscopically, then, the rocks are dark-colored porphyries containing augite phenocrysts and are therefore augite melaphyres according to the field classification of Pirsson."

The augite phenocrysts range in size from about 1 mm. to as much as 10 mm. in longest dimension. Both the breccia fragments and the matrix contain augite phenocrysts, although, they seem to be somewhat more abundant and more distinct in the fragments.

The groundmass is altered considerably so that its original character is obscure. Roughly square, crystal outlines can be observed under the microscope and it is presumed that these represent feldspar originally present. The alteration products that make up the groundmass are epidote, sericite, chlorite, quartz, and a small amount of calcite and pyrite.

As seen with the microscope there is no noticeable difference between a thin section of a breccia fragment and one of the matrix. This observation is in harmony with the fact that on a fresh surface the fragmental character is not readily apparent.

Origin

There can be no doubt that the Douglas Island volcanics are extrusive rocks. The fact that they are so intimately interbedded with the neighboring sedimentary rocks is perhaps the most conclusive evidence. The lack of contact effects, the extreme variation in fragmental texture from place to place, and the rounded fragments are all indicative of a terrestrial origin.

Obviously, then, the Douglas Island volcanics are extrusive volcanic rocks formed under conditions that resulted in practically the entire sequence acquiring a brecciated or fragmental character. What were these special conditions of environment that caused such a vast accumulation of exclusively volcanic breccia?

It appears fairly certain that the breccias accumulated in a geosyncline that also was receiving detrital material from adjacent land masses. This detrtus is now represented by the great thicknesses of slate and graywacke above and below the volcanic breccias. Deposition to produce the slate and graywacke was probably more or less continuous, but, at time volcanic activity released vast quantities of volcanic material into the basin of deposition. The contribution of volcanic material at the beginning and final stages of the main period of volcanic activity resulted in the interbedded volcanic breccias and the normal sedimentary slates and graywackes at the margin of the main belt of the Douglas Island volcanic group. If, as may reasonably be supposed, the slates and graywackes are marine sediments, then it follows that the breccias which are so intimately interbedded with them, are likewise marine accumulations. Of course, it is reasonable to assume that at times the volcanic material may have accumulated to such a great thickness that at times it filled the basin of deposition. In general, though, the most reasonable explanation is that the breccias are submarine accumulations.

The fact that the Douglas Island volcanic group is made up almost entirely of breccia is difficult to explain. The fact that the fragments and matrix are identical in composition and texture leads to the supposition that rock is a flow breccia in the sense that the material actually flowed from its source and remained fluid during the time that it was moving. As the lava cooled and began to crystallize it was broken up and the partially solidified fragments again incorporated in the still fluid portion of the lava. Those fragments that had completely solidified retained their angularity as they sank in the still remaining fluid lava, whereas the somewhat "mushy" fragments were founded and in some cases flattened or drawn out as they settled into the fluid lava. This process was probably repeated many times until but little of the fluid lava remained and most of the flow was made up of fragmental material. Some flows extended for greater distances than others. Thus, the area on the north side of Douglas Island was at a considerable distance from the vent (or vents) from which the volcanic breccia was extruded and consequently only a few narrow bands are present.

Age

Of all the localities in southeastern Alaska where volcanic breccia is found, only on Gravina Island is there any fossil evidence as to their age. Chapin (1919, p. 96) collected fossils from this locality and submitted them to T. W. Stanton who reported them as Aucella sp. of probable upper Jurassic age, but possibly lower Cretaceous. Fram Chapin's description the lithology of the Gravina Island volcanic breccias appears similar to that of the Douglas Island volcanic group, but this is the only basis for assuming that the two groups of rocks are of similar age. Considering that the two groups of rocks crop out at least 200 miles apart it is certainly unlikely that the similar lithology is a reliable criterion of similar age.

In the Wrangell district Buddington (1923, pp. 53-54) assigned a Jurassic age to the volcanic breccias that occur in that district. This age assignment is based only on the lithologic similarity of the volcanic breccias of the Wrangell district with those of Gravina Island. No fossils were found associated with the breccias in the Wrangell district and the structural evidence as to their age, according to Buddington, is indeterminate.

In the Juneau area no fossils were found in the Douglas Island volcanic group of rocks. Upper Triassic fossils were found in the overlying Gastineau volcanic group in the Sheep Creek Basin south of Juneau (Martin, 1926, p. 95). Consequently the Douglas Island volcanic group is tentatively classified as pre-upper Triassic, and, because there is no apparent stratigraphic break between the

Douglas Island volcanic group and the overlying rocks between it and the fossils found in the Gastineau volcanic group, it is tentatively assumed that their age is middle or lower Triassic, but quite possibly are Paleozoic.

Other localities in southeastern Alaska have been described as having volcanic breccias similar to those of the Juneau area. These localities, as described by Buddington and Chapin (1929, p. 166) are as follows:

"To the southeast the greenstone volcanic rocks form most of the Glass Peninsula, Admiralty Island, and a belt striking across Farragut Bay, on the mainland. They are again exposed as a narrow band intercalated in graywacke on the east side of Slind Slough and as a belt east of Point Alexander, Mitkof island. They form Vank and Sokolof Island and a belt on the north end of Etolin Island at Olive Cove and Anita Bay. In the Ketchikan district they form Onslow Island and the west part of the Cleveland Peninsula and extend southeast along Tongass Narrows, Gravina, Annette, and Mary Islands, and the coast north of Cape Fox."

All of these volcanic rocks, including the Douglas Island volcanic group, have been tentatively assigned to the Jurassic by Martin (1926, p. 256) and Buddington and Chapin (1929, p. 167), but their evidence for such an age assignment is extremely tenuous and they stated that the age as assigned is little better than an intelligent guess.

TREADWELL SLATE

Distribution and Character

The Treadwell slate occurs in the Juneau area along the northeast side of Douglas Island. The formation is bounded on the southwest by the Douglas Island volcanic group; its northeast boundary lies beneath Gastineau Channel. It disappears to the southeast beneath the waters of Stephens Passage and has not been recognized beyond. To the northwest the author has traced the Treadwell slate through the Eagle River region and beyond Berns Bay until it finally disappears beneath Lynn Canal. In the Eagle River and Berns Bay regions the Treadwell formation comprises a large part of the "Berners formation" described by Knopf (1911, pp. 12-17; 1912, pp. 13-18). Near Juneau the Treadwell formation largely consists of fine-grained, black slate and phyllite with extremely well development cleavage, whereas to the northwest an increased amount of graywacke and a few conglomerates are present in the formation which, however, is predominantly made up of black slate and phyllite.

The Treadwell slate is included in the "slate-greenstone" band described by Spencer (1906, pp. 16-18). The Treadwell slate is separated on the geologic map (in pocket) from the overlying Thane volcanic group and the underlying Douglas Island volcanic group on the basis of its distinctive lithologic character. All of the productive mines on Douglas Island were in mineralized diorite sills that intruded the Treadwell formation.

Near the southeast end of Douglas Island, in the vicinity of Nevada Creek, the Treadwell slate crops out over a width of less than half a mile. To the northwest in the vicinity of Douglas the belt has widened to nearly a mile, and at this position the southwestern boundary of the slates turns to the westward and at the northwestern end of Douglas Island the slate belt is almost three and one-half miles wide. All along the northeast shore of Douglas Island is a conspicuous zone of low relief which is underlain almost entirely by the Treadwell formation.

The southwest boundary of the Treadwell slate shown on the accompanying geologic map is somewhat arbitrary. There is no definite line of demarcation between it and the Douglas volcanic group. Between the two groups of rocks is a transitional zone, a few hundred feet wide in the vicinity of Nevada Creek and over a thousand feet wide in the vicinity of Lawson Creek, consisting of interbedded slate, tuffs and narrow bands of volcanic breccia. For cartographic purposes the boundary between the two formations has been drawn where it was believed the proportion of volcanic breccia and slate is about one-half.

The northwest boundary of the Treadwell slate with the overlying Thane volcanic group is not exposed in the area covered by this report -- it being concealed beneath Gastineau Channel. In the Eagle River region on the ridge between Lemon Creek and Mendenhall River is exposed the contact between the Gastineau volcanic group and the Treadwell slate. This contact is transitional, consisting of interbedded slates and bedded tuffs.

In general all of the Treadwell formation has a pronounced cleavage parallel to the stratification. The general strike of the stratification and cleavage is northwest-southeast, and the dip is nearly everywhere to the northeast. The dip ranges from 30 degrees to vertical, but mostly is about 50 to 70 degrees. Locally the beds are crumbled and folded into small flexures a few feet across. The crumbling is most prevalent near intrusive sills of diorite and the lack of any consistency of the axes of the folds suggests that the folding is to be attributed to causes attendant to the intrusion of the sills.

The Treadwell slate like all of the rocks of the region has been metamorphosed by the regional metamorphism during the intrusion of the Coast Range batholith. The affect of metamorphism has been to indurate the original sediments and to slightly recrystallize them to the extent that a slaty cleavage was produced. The diorite intrusives have affected the slates but little; in places the slates appear to be converted to dense blacky hornfels, but at other places near the diorites the slates are seemingly unaffected by igneous effects.

Lithology

The Treadwell formation is composed dominantly of extremely fine-grained, dense, fissile, black slate and phyllite. The black color is due to finely disseminated graphite which originally was organic material that was converted to graphite during metamorphism. Also included within the mapped limits of the Treadwell formation are beds and lenses of graywacke and one bed of conglomerate. The latter crops out below the Treadwell dike on the slope west of the town of Douglas. It is about 20 feet wide and contains pebbles of quartzite, dense black slate, and a medium-grained, light-gray granitic rock. The graywacke is gray to green in color and composed of fragments of feldspar, quartz, augite, hornblende, and chlorite imbedded in an argillaceous cement.

Origin

The Treadwell slate is thought to be entirely marine and to have accumulated in a subsiding basin of deposition. Evidence for marine deposition is not conclusive. The only fossils that have been found in the formation are a few leaf impressions found at Berners Bay and they do not contribute much information as to environment of deposition. The fine bedding, fine-grained character of the sediments, and widespread extent of the Treadwell formation are somewhat indicative of marine deposition. Lack of cross bedding and lack of abrupt changes in lithologic character indicate uniform conditions of deposition such a might obtain in a marine basin of deposition. The large amount of organic material, now represented by the graphite in the slates, suggests a marine environment of deposition, probably in quiet, non-aerated waters that permitted the organic matter to accumulate and be preserved. Subsequent orogenic disturbances have converted the original carbanaceous shales into slates.

Age

No fossils have been found in the Treadwell formation in the Juneau area. However at Berners Bay leaf impressions were found by Knopf (1911, p. 17) in sediments that are the northwesterly extension of the Treadwell formation. These fossils indicate a Mesozoic age and possibly a Jurassic age, but the age assignment is most tentative. After a complete appraisal of all evidence the author is of the opinion that the Treadwell slate is probably Triassic.

GASTINEAU VOLCANIC GROUP

Distribution and Character

In the area covered by this report the Gastineau volcanic group crops out along the northeast shore of Gastineau Channel and in the area lying northeast for a distance of about two miles from the channel. To the northwest of the Juneau area the Gastineau volcanic group has been mapped by the author as far as Berners Bay; to the southeast the group extends across Taku Inlet and to the southeast along the coast at least as far as Molkham Bay.

The Gastineau volcanic group is part of the "slate-greenstone" band that Spencer (1906, pp. 16-18) described and mapped as extending from Port Houghton to Haines. It is not known if the Gastineau group as defined herein extends for this entire distance along the coast. The Gastineau volcanic group was not differentiated by Knopf (1912, pl. 5) in the Eagle River region to the northwest of the Juneau area, although the writer has recognized this group of volcanic rocks in the Eagle River region and has found them to be included in the group of rocks that Knopf mapped as "schist (metamorphic phase of Berners formation)."

Possibly the Gastineau volcanic group is represented by Knopf's (1911, pp. 19-21) "altered amygdaloidal basalts" in the Berners Bay region.

In the Juneau area the contact between the Gastineau volcanic group and the underlying Treadwell formation is concealed by Gastineau Channel, but on the slope on the northwest side of Mendenhall Glacier in the Eagle River region the contact between these two formations is seen to be conformable and transitional. The contact between the Gastineau volcanic group and the overlying Perseverance slate is well exposed in Sheep and Gold creeks and is conformable and transitional.

The thickness of theexposed portion of the Gastineau formation in the Juneau area ranges from 6,000 to 7,000 feet and its true thickness is not know because part of it is concealed by the Gastineau Channel. To the northwest at Mendenhall Glacier where the entire width of the Gastineau formation is exposed it has thinned to approximately 4,000 feet. The greatest known thickness of the formation is about 8,000 feet on the northwest shore of Taku Inlet.

For cartographic purposes the Gastineau volcanic group is differentiated into two distinct types -- one type characterized by the dominance of finely bedded tuffs and the other by the dominance of lava flows.

The writer has included within the Gastineau volcanic group the two formations designated by Martin as the Gastineau volcanic group (Martin, 1926, pp. 92-95) and the Thane volcanic group (Martin, 1926, pp. 251-252). Martin states that the original data for these two formations were taken from an unpublished U. S. Geological Survey report by H. M. Eakin and A. C. Spencer entitled "Geology and ore deposits of Juneau, Alaska." A subsequent revision of this report by Eakin (1922) did not distinguish a Thane volcanic group. It is apparent that the rocks of Martin's Thane volcanic group would more or less correspond with the bedded tuffs in the lower part of the Gastineau formation as defined in this report. It is the writer's opinion that the term "Thane volcanic group" is a useful designation and might well be retained. However, because the bedded tuffs so characteristic of the Thane volcanic group occur in the lower part, it is considered more logical to depict rock types on the map instead of attempting to map a separate Gastineau group of lavas and a Thane group of tuffs.

The rocks mapped as bedded tuffs include as the dominant rock type, green, medium-grained, finely bedded sediments in which chlorite is the most conspicuous mineral. Lesser amounts of limestone, black slate, quartzite, and lava flows are included. Agglomerates are very common in the lower part of the Gastineau volcanic group.

Lithology

The rocks included within the Gastineau volcanic group include dominantly volcanic rocks with subordinate, but persistent beds of black slate, calcareous graywacke, and tuffaceous slate. The volcanic rocks include both lavas and rocks composed mostly of volcanic ejectamenta; these two types of volcanic rocks are differientated on the geologic map of Juneau and vicinity.

The rocks mapped as lava flows include as the dominant rock-type greenish-black, massive, andesitic and basaltic lavas, and in addition include tuffs and black slate. The lavas are commonly porphyritic; the basalts are characterized by augite phenocrysts and the andesites by feldspar phenocrysts.

The pyroclastic rocks are dominantly fine-grained tuffs. The fragments in the more massive beds are as much as one-quarter to one-half inch across. Thinner beds are composed of finer clastic material. All of the pyroclastic beds are well-bedded with individual beds persisting for long distances.

The slates and graywackes of the Gastineau volcanic group generally are black graphitic types, very thinly bedded, with well-developed cleavage parallel to the bedding. Intergradation between the slates and tuffs is quite common.

Origin

The presence of sedimentary beds of tuff, black slate, and graywacke, interbedded with lava flows indicate that marine conditions prevailed during the deposition of most, if not all, of the Gastineau volcanic group. The presence of marine fossils in a black slate band near the top of the formation is proof that this particular unit is marine. On the northwest shore of Taku Inlet near the mouth of Grindstone Creek are pillow lavas suggesting a subaqueous origin. There is no evidence to indicate that any other conditions prevailed during deposition of the Gastineau volcanic group and it is probable that the entire assemblage accumulated under marine conditions.

As was postulated in the discussion of the Douglas Island Volcanic group, it is thought that deposition of clastic material, represented by the Treadwell slate and Perseverance slate, was fairly constant and continuous and that from time to time large quantities of ash and flows were contributed to the basin of deposition. The Gastineau formation obviously represents a time of considerable volcanic activity.

It is interesting to note that both the upper and lower parts of the Gastineau volcanic group are dominantly tuffaceous whereas the middle part is dominantly flows. It is apparent that the beginning and waving stages of volcanic activity consisted of explosive action only whereas during the maximum of volcanic activity vast amounts of lavas were extruded.

– at Taku Inlet pillow flows at top on & W of Pt. Bishop.

The whole Gastineau volcanic group has suffered intense stresses that have induced slaty cleavage in all of the fine-grained sediments and has sheared the more massive flows. That the shales have recrystallized is evident in their content of graphite and high degree of induration. The tuffs are altered to chloritic and actinolite schists and at places even the lavas have recrystallized into micaceous and amphibolitic schists. The prevailing green color of the Gastineau volcanic group is caused by the ubiquitous chlorite that is present in practically all of the volcanic rocks and is responsible for the local term greenstone that is generally applied to these rocks.

Age

Fossils, indicate of Upper Triassic age, were collected by Spencer and Eaken (1922) from a black slate band within the Gastineau volcanic group near the head of Sheep Creek basin. A report by John B. Reeside of the U. S. Geological Survey on these collections is as follows:

"9844. Sheep Creek - Grindstone Creek divide.
Arcestes or Paraganides, sp. indent.
Fragment of an ammonite very like Trachyceros (Protrochyceros) lecontei Hyatt and Smith.

9845 Head of Sheep Creek near Goldstein Creek divide.
Atractites cf. phillippi H. and S.
Halobia cf.superba mosisj.
Impression of an undetermined ammonite.

9846 Sheep Creek basin. Head of west tributary.
Halobia cf. superba mosisj.

"These forms belong to the Halobia cf. superba fauna of the Upper Triassic and are probably of Kornic age rather than Noric."

The lack of any stratigraphic break within the Gastineau volcanic group indicates the entire group probably is Upper Triassic.

PERSEVERANCE SLATE

Distribution and Character

The Perseverance slate crops out on the mainland east of Juneau between the underlying Gastineau volcanic group and the overlying Clark Peak Schist. It is the uppermost group of rocks of Spencer's (1906, pp. 16-17) "slate-greenstone" band. All of the important mineral deposits of the Alaska-Juneau lode system occur within the Perseverance slate band.

Within the area covered by this report the Perseverance slate crops out in a northwest-southeast band about one-quarter of a mile wide in Salmon Creek and about a mile wide near the head of Sheep Creek. In Gold Creek the Perseverance slate is offset by the Silver Bow fault. Beyong the Juneau area the Perseverance slate was traced to the northwest as far as the head-waters of McGinnis Creek in the Eagle River region where it is cut off by the Coast Range batholith. Knopf (1912, pl. 2) did not recognize the Persev-erence slate when he mapped the Eagle River region, but included it within his "schist (Metamorphic phase of Berners formation)." Southeast from Juneau the writer has traced the Perseverance slate to Taku Inlet where it is exposed on both sides of the Inlet. Buddington and Chapin (1929, pl. 1) have shown on their geologic map that a black slate band, corresponding with the Perseverance slate, extends from Juneau as far south as Holkham Bay, but it is not known if the slates as defined herein are continuous throughout the whole distance.

The dominant rock in the Perseverance formation is black slate and phyllite, but also included within the mapped limits of the formation is thin-bedded quartzite and thin-bedded limestone; all gradations are found between black slate, quartzite and limestone. The latter exists only as a few thin beds too small to depict on the accompanying geologic map. Bedding is difficulty recognized in the black slate for it has been obliterated by the prevalent slaty cleavage that has been induced in them. Bedding is readily seen in the quartzites and like the bedding in the slates, is parallel to the cleavage except at places where small drag folds and plications cut across the cleavage. Cleavage is not as prominant in the quartzites as in the slates.

Lithology

The black slates are fine-grained, highly fissile rocks whose black color is caused by their graphite content. The graphite was carbonaceous matter, originally present in the sediments, that has been subsequently metamorphosed. The other minerals in the slates are quartz, chlorite, and sericite that apparently are recrystallized from quartz and clay minerals originally present in sediments.

The quartzites are fine-grained, finely bedded, light colored rocks composed dominantly of quartz. Other minerals present are pyrite and sericite and at places a little calcite. The limestone are entirely recrystallized and composed entirely of calcite.

A somewhat unusual rock, locally known as a "spotted schist" is found in the Perseverance formation associated with quartzite. It may be described as a slaty quartzite with dark spots randomly distributed on the bedding planes and cleavage surfaces. Under the microscope the spots are revealed to be composed of quartz and sericite (at places biotite), the same minerals that make up the matrix. The minerals in the spots, however, are more coarse grained than those of the matrix and the sericite is randomly oriented whereas the sericite of the matrix is oriented parallel with the cleavage of the rock.

It would appear that the spots represent places where recrystallization of slaty quartzite has advanced beyond that of the rest of the rock. The lack of preferred orientation of the sericite in the spots indicates that recrystallization took place under conditions of undirected stress.

Origin

The Perseverance slate, like all the other sedimentary rocks in the Juneau area, is thought to represent original marine sediments subsequently metamorphosed. Like the Treadwell slate the Perseverance slate probably accumulated in quiet waters in which circulation was poor, resulting in an accumulation of considerable organic matter mixed with the sediments. The considerable increase of quartzite in the Perseverance formation over that in the Treadwell formation suggest that the competency of the currents carrying the detrital material had increased during Perseverance time. The considerable quantities of what is thought to have been coarse detrital material in the overlying Clark Peak schist suggests that the competency of the waters entering the basin of deposition continued to increase long after the deposition of the Perseverance slate.

Age

No fossils have been found in the Perseverance slate, but the lack of a stratigraphic break between it and the underlying fossiliferous horizona containing Upper Triassic fossils, strongly indicates that the Perseverance formation, at least in part, is Upper Triassic.

CLARK PEAK SCHIST

Distribution and Character

The Clark Peak schist occupies the intervening space between the Perseverance slate and the Coast Range batholith and forms a continuous band from two to three miles wide along the southwest side of the batholith. The southwest boundary of the schist with the underlying Perseverance slate is an entirely arbitrary line. For mapping purposes it has been drawn approximately through the places where biotite first appears as one travels northeastward from the Perseverance slate. It is unlikely if any two persons would place the boundary line in the same position. In effect, then, the boundary between the Perseverance slate and the Clark Peak schist is a boundary between two metamorphic zones, although in the Juneau area this metamorphic boundary more or less coincides with a boundary between black slates and other types of sediments.

The Clark Peak schist extends northwest of the Juneau area to a point a few miles northwest of Mendenhall Glacier, where it is cut off by the edging over of the Coast Range batholith. Knopf (1912, pp. 20-22) mapped a band of schist adjacent to the Coast Range batholith in the Eagle River region.

If the W. margin of the "Bath." is metamorphic this isn't possible. S

These schists are in large part the metamorphic equivalent of the Perseverance slate and the Gastineau volcanic group and are not, except in the vicinity of Lemon and Nugget creeks, the equivalent of the Clark Peak schist.

The Clark Peak schist extends southeastward as far as Taku Inlet and probably extends beyond, but it was not traced any farther. Buddington and Chapin (1929, pl. 1) show a belt of "crystalline schist and phyllite" along the southwest edge of the Coast Range batholith all the way from Juneau to Portland Canal. This unit includes the Clark Peak schist in the Juneau area and probably is the metamorphic equivalent of various different rock units to the southeast.

The prevailing rock type of the Clark Peak schist is quartz-biotite schist and quartz-muscovite schist. However, a diverse variety of other rocks are present in the formation; among these are marble, quartzite, black phyllite, hornblende schist, quartz-garnet-mica schist, kyanite schist, chlorite schist and quartz-feldspar schist. The Clark Peak schist is almost entirely the metamorphic equivalents of original shales, sandstones, and limestone, with lesser amounts of extrusive igneous rocks. Of these sediments shal and sandstone were the most abundant.

All of the rocks of the Clark Peak schist possess a well-defined schistosity which largely parallels the original bedding.

Lithology

The almost infinite variety of rocks that collectively comprise the Clark Peak schist makes a description of the rock types an almost endless task, and, as a consequence, only the more general types will be mentioned.

Quartz-mica schist is the most common rock type in the Clark Peak schist. Both biotite and muscovite varietiess are found. The rocks are entirely recrystallized so that they are composed of interlocking grains of quartz with medium-grained plates of mica oriented parallel so as to give the rock its schistose structure. Certain thin layers within the rock are most micaceous than others; apparently this thin banding results from differences in the composition of the original sediment. Pyrrhotite is a common accessory mineral and accounts for the brown staining that covers the weathered outcrop.

In addition to the common quartz-mica schist there are many varieties depending upon the prominence of various accessory minerals. Thus, there are hornblende schist, kyanite schist, garnet schist, sericite schist and chlorite schist. Near some of the large intrusives the schist is feldspathic, and in some instances it has the characteristic structure of augen gneiss, so that it is questionable whether the rock is derived from original sediments or from intrusive material.

The accessory minerals at places are porphyroblastic and give the rock a spotted appearance. Red garnet and feldspar occur most commonly in this way. The sweep of cleavage planes of mica around such nucleii give characteristic "knoten-schiefer" rocks.

Persistent marble bands occur within the Clark Peak schist, although they are not numerous. The largest band is best exposed where it crosses Granite Creek; here there is 100 feet of almost pure, white, medium-grained marble and 115 feet of mixed calcareous and siliceous rock. Within the marble are thin partings and irregular contorted bodies of quartz-biotite schist which probably represent originally distinct strata within the limestone. The contorted shapes of some of these bodies suggest actual flowage of the limestone.

Origin

The Clark Peak schist is largely the metamorphic equivalent of sedimentary rocks. It is not possible to state with any degree of certainty whether the sediments accumulated in a marine or continental environment. The considerable length of the westernmost marble bed shown on the accompanying geologic map suggests that part of the sediments were marine. Considerably greater amounts of coarse clastic material were deposited in what is now the Clark Peak schist than in any of the underlying sedimentary rocks. This fact indicates transportation by more competent currents and that the source of the sediments was undergoing more active erosion than previously.

Age

No fossils were found in the Clark Peak schist and it is doubtful if any will ever be found for any that may have been present would have been destroyed by the intensive metamorphism to which the rocks have been subjected. Assuming that there is no structural break between the Clark Peak schist and the underlying rocks, it is obvious that the Clark Peak schist is younger than the underlying Gastineau volcanic group of Upper Triassic age. Martin (1926, p. 94) regarded the Clark Peak formation as Paleozoic for he says:

"The Clark Peak schist***does not bear a notable resemblance to any known Triassic rocks and as it lies on the strike of the Carboniferous rocks of Taku Harbor and other localities south of Taku Inlet, the writer believes that it belongs in the Paleozoic, where it was formerly placed by Spencer. It may, however, include some infolded Triassic beds."

When one examines the geologic map of southeastern Alaska, prepared by Buddington and Chapin (1929, pl. 1) it is readily seen that the rocks of Taku Harbor do not lie on the strike of the Clark Peak schist -- rather they lie considerably west of the strike of the Clark Peak schist.

Because the Clark Peak schist overlies the Upper Triassic Gastineau volcanic group and is intruded by the Upper Jurassic-Lower Cretaceous Coast Range batholith, it follows that the age of the Clark Peak Schist is somewhere between Upper Triassic and Upper Jurassic-Lower Cretaceous.

COAST RANGE BATHOLITH

Distribution and Character

The Coast Range batholith occurs along the northeast edge of the Juneau area where it bounds the metamorphic rocks. It is the largest batholith on the North American continent, and extends from the Fraser River in British Columbia for over 1,000 miles northwestward into Yukon Territory. It forms the backbone of the Coast Range along the northwest coast of British Columbia and southeastern Alaska from Vancouver to Skagway.

The batholith attains a maximum width of about 110 miles in British Columbia and gradually thins northwestward to about 35 miles in the vicinity of Juneau and Skagway.

Buddington made the only detailed study of the batholith in southeastern Alaska; his studies were confined to that portion of the batholith from Portland Canal to the Stikine River. He summarizes his observations as follows (Buddington and Chapin, 1929, p. 181):

***there is a pronounced variation in composition across the batholith from southwest to northeast. The southwest border facies of the batholith, in a band 5 to 15 miles wide, is quartz diorite; the core 15 to 25 miles wide, has the average composition of a grandiorite, quartz monzonite, and quartz diorite; and the eastern border facies, 10 to 15 miles wide, is quartz monzonite. *** The changes from one type of rock to another appear to take place rather abruptly, but no evidence of brecciation of one variant by another was seen, except in the small masses of gabbroic and ultrabasic rocks. Nevertheless, certain features suggest that we may be dealing with a group of very closely related interlocking batholiths."

Relation to other formations

The contact between the Coast Range batholith and the bedded rocks dips northeasterly parallel to the foliation of the intruded rocks. This parallelism is only approximate, however, as may be seen from the large sill that terminates on the ridge back of Mt. Juneau. The transgressive nature of the main batholithic contact is shown also by the gradual cutting off of successively more westerly formations to the northwestward. For example, east of Juneau the Coast Range batholith is separated from the Perseverance slate by some 2 or 3 miles of Clark Peak schist, yet only 15 miles northwest along the strike of the bedded rocks the batholith lies against the Gastineau volcanic group.

Within the main mass of the batholith are numerous bands of metamorphic rock, some several hundred feet wide and thousands of feet long. The trend of these bands is the same as that of the bedded rocks away from the batholith, namely northwest-southeast and dipping steeply to the northeast. These large bands are considered to be large undigested inclusions, and all stages down to hand-size inclusions can be observed. The inclusions are not shown on the map for they are in the inaccessible portions of the batholith where observation of them has been made only from the air.

The gneissoid structure of the Coast Range batholith parallels that of the bedded rocks and is most prominently developed near the contact with the adjacent bedded rocks. The gneissoid structure ranges from a few hundred feet thick to as much as 1 or 2 miles thick. At some places it is difficult, if not impossible, to distinguish the gneissic igneous rock from the gneissic metamorphic rock. In part the gneissic structure is a primary structure formed during solidification of the magma and in part the result of dynamic metamorphism and granitization of the adjacent sediments.

Lithology

The main Coast Range batholith was carefully studied in the Ketchikan and Wrangell district by the Wrights (1908, pp. 63-65). Their results are quoted below:

"Although the composition of the Coast Range granodiorites vary considerably from point to point, it is desirable to ascertain the approximate average composition of the entire mass. To this end seven typical specimens were selected from different parts of the range. These specimens were chosen with special regard to their abundance and general distribution throughout the area, abnormal and rare types being disregarded altogether. Each of these specimens was studied in detail under the microscope, and a careful estimate of the relative quantity of each mineral in the rock was made from the thin sections by the Rosiwal method. Although the values thus obtained are necessarily only first approximations, they represent roughly the general mineral content of the Coast Range granodiorite.

"The following average mineral composition was thus obtained:

Average mineral composition of the Coast Range intrusive.

Quartz	19.4	Pyrite	0.1
Orthoclase	6.6	Titanite	1.3
Andesine ($Ab_{56}An_{44}$)	47.4	Epidote	3.5
Hornblende	7.6	Chlorite	0.1
Biotite	11.6	Calcite	0.1
Apatite	0.6	Kaolin and muscovite	0.8
Magnetite	0.9		
			100.0

"The average specific gravity, 2.77, was determined by weighing the hand specimens in air and then in water.

"From these data the average chemical composition was calculated by assuming for the hornblende and biotite the composition of like minerals from a similar rock from Butte, Mont.

Average chemical composition of the Coast Range intrusive.

Constituent	Per cent	Molecular ratio
SiO_2	61.0	1.017
TiO_2	1.0	0.013
Al_2O_3	17.5	0.171
Fe_2O_3	1.6	0.010
FeO	2.7	0.038
MnO	0.1	0.001
MgO	2.4	0.060
CaO	6.9	0.123
Na_2O	3.3	0.053
K_2O	2.3	0.024
H_2O	0.9	0.050
P_2O_5	0.3	0.002
	100.0	

"This chemical and mineral composition places the rock in the family of the quartz diorites, of the type tonalite according to the usual classification. ***"

"The amount of titanite is unusual and is characteristic of many of the Coast Range intrusives. The highly lustrous, well-shaped crystals of this mineral glisten in the sunlight and attract the attention of the most casual observer. The hornblende occurs usually in dark prismatic crystals, noticeable for the excellent prismatic cleavage and the lack of terminal faces. Many biotite flakes are hexagonal and deep brown in transmitted light. A few apatite crystals are visible to the unaided eye, but this mineral occurs generally in fine hexagonal crystals of microscopic dimensions. Pale-green veinlets of secondary epidote, which follow fracture planes in the granodiorite, are not rare.

"These even-grained rocks usually have the normal, sharply defined, granitoid texture. However, gradations to holocrystalline porphyritic phases, due to the superior development of the feldspars, occur. Gneissic structure is common near the western margin of the Coast Range belt. In some places the development of gneissic structure in the granite has been so far advanced and the recrystallization of the neighboring invaded sediments to gneiss has been so thorough that it is difficult to define the precise limits of the original intrusive granite."

Buddington (Buddington and Chapin, 1929, pp. 210-212) gives the following results of a composite sample of 14 specimens from the western part of the Coast Range batholith:

Chemical analysis of composite sample of quartz diorite

(J. G. Fairchild, analyst)

SiO_2	59.56
Al_2O_3	16.18
Fe_2O_3	1.94
FeO	5.61
MgO	2.86
CaO	6.26
Na_2O	3.40
K_2O	2.62
H_2O-	0.04
H_2O+	0.82
TiO_2	0.96
P_2O_5	0.25
	100.50

The approximate mineral composition as determined by Buddington (Buddington and Chapin, 1929, p. 212) of certain rocks from the Coast Range batholith, is given below:

Average mineral composition of Coast Range batholith in southeastern Alaska

	Andesine	Hornblende	Biotite	Quartz	Potassic Feldspar	Accessory minerals
Average of 21 specimens from west border of Coast Range batholith.	54	11	12	20	2	1¼
Average of 4 specimens, hornblende and biotite approximately equal.	59	10½	8½	19	1	2
Average of 5 specimens; hornblende in excess of biotite.	54½	15	7	19	3	1½
Average of 8 specimens; biotite in excess of hornblende.	59	3	12	23	2	1
Average of 2 highly ferromagnesian specimens; hornblende in excess of biotite.	44½	22	14	18	-	1½
Average of 3 highly ferromagnesian specimens; biotite in excess of hornblende.	43½	12	22	19	2	1½

The data recorded above pertain only to the southwestern border of the southern part of the Coast Range batholith in southeastern Alaska. However, in the absence of specific data to the contrary they are believed to be representative of the northern part of the batholith.

In the Juneau area the principal rock type of the Coast Range batholith is quartz diorite consisting of coarse-grained plagioclase, quartz, biotite, and hornblende; the most characteristic accessory mineral is yello sphere and the other accessory minerals are apatite, pyrite, and magnetite. In the main part of the batholith away from the gneissic borders the quartz diorite is remarkably fresh and unaltered. The plagioclase which comprises about 60 per cent of the rock, ranges from $Ab_{40}An_{60}$ to $Ab_{70}An_{30}$ and averages about $Ab_{50}An_{50}$; quartz comprises about 20 per cent of the rock and hornblende and biotite together with the accessory minerals comprise the remaining 20 per cent of the rock.

In the gneissic phases and in some of the larger sills that cross Granite Creek the cataclastic nature of the rock is readily apparent in the hand specimen. The most prominent cataclastic feature is the augen character of the feldspars which under the microscope are seen to have their corners crushed and to be imbedded in a mosaic of granular quartz. The biotite is arranged in a fashion to appear to wrap around the fedlspar augen.

Some of the variants of the Coast Range intrusive are well revealed in the three outlying sills that cross Granite Creek. The outermost, or number one, sill is about 300 feet wide. The central portion of the sill has a granitoid texture whereas near the borders it is increasingly gneissoid in such a manner that it is impossible to determine the place where the intrusive rock ends and the Clark Peak schist begins. The rock is an altered biotite-quartz-monzonite composed of approximately 25 per cent of quartz, 35-40 per cent of othoclase, 25 per cent of clinozoisite, with the remainder about equally divied between plagioclase, biotite, and chlorite, and with minor accessories of apatite and titanite. Clinozoisite has obviously been derived from plagioclase.

The middle, or number two, sill is about 1800 feet wide; it terminates to the northwest on the ridge back of Mt. Juneau. It is a gneissoid biotite-quartz monzonite with well-developed feldspar augen. The augen are othoclase, with crushed corners and edges, in a groundmass of quartz and plagioclase ($Ab_{60}An_{40}$). The latter is considerably altered to clinozoisite. The accessory minerals, in addition to biotite, are hornblende, titanite and apatite.

The inner, or number three, sill is about 700 feet wide. Its borders are sharply defined and it does not have the gneissoid texture that the other sills have. It is a hornblende-quartz monzonite and is very fresh appearing, completely lacking the conspicuous amounts of clinozoisite present in the other sills. It obviously has not suffered the dynamic metamorphism that the other sills have. In addition to hornblende the other accessory minerals are titanite, pyrite and apatite.

Origin

The field relations prove beyond any doubt that the Coast Range batholith is intrusive into the bedded rocks lying to the southwest of the batholith. It is equally obvious that the batholith has stoped and replaced large quantities of the invaded sediments. The presence of thousands of inclusions of gneiss and schist, both large and small, within the batholith, and the overall transgressive character of the southwest contact all attest to the displacement and replacement by the batholith of enormous amounts of sedimentary material.

The intrusion of the batholith, at least during part of the process, was accompanied by a strong dynamic forces which resulted not only in metamorphism of the invaded sediments but also the development of gneissic structure in the nearly completely consolidated batholith. The author believes the bordering gneissic facies of the batholith are due to dynamic stresses and not due to flow within the batholith. The widespread cataclastic effects within the gneissic border phases of the Coast Range batholith indicate that oriented forces prevailed during emplacement of the batholith and some of the large related sills.

Age

Within the Juneau area there are no specific data on which to determine the age of the Coast Range batholith. The batholith intrudes the Clark Peak schist, Perseverance slate, and the Gastineau volcanic group, and obviously is younger than these rocks. As discussed in other sections of this report the Gastineau volcanic group is Upper Triassic.

On some of the islands of southeastern Alaska it is known that some of the batholithic and stock-like intrusive rocks, lithologically similar to the Coast Range batholith, are definitely older than Eocene (Buddington and Chapin, 1929, p. 252). On Chichagof Island, Overbeck (1919, pp. 109-112) describes intrusives that cut fossiliferous rocks of Upper Jurassic age. Buddington (Buddington and Chapin, 1929, p. 253) states that he:

" *** is convinced that on Admiralty Island intrusions of the Coast Range type cut beds which, where not metamorphosed, carry the fossil Aucella crassicollis and which are therefore probably of lower Cretaceous age."

In the Hyder district there definitely are two periods of intrusion (Buddington, 1929, pp. 22-23). The older intrusive, the Texas Creek batholith intrudes the Hazelton series of known Jurassic age, and is in turn intruded by the Hyder and Boundary batholiths.

It seems reasonable to assume that much of the Coast Range batholith is a composite batholith made up of igneous material intruded at various times. Thus in one place a particular intrusion may be Upper Jurassic and at another Lower Cretaceous.

Buddington (Buddington and Chapin, 1929, p. 252) writes as follows with respect to the age of the Coast Range batholith in nearby British Columbia:

"To the northeast on the east side of the batholith in the Whitehorse district, Yukon Territory, the intrusive rocks are reported by Cookfield (Cookfield and Bell, 1926, pp. 32-33) to cut rocks of Middle Jurassic age and therefore to be probably of Upper Jurassic age or later. Hanson (1924, p. 37) reports that on the east side of the batholith, in British Columbia, between Skeena River and Stewart, the Coast Range batholith intrudes the Hazelton group (Jurassic) but does not intrude the Skeena (Lower Cretaceous) series.He says: 'It is therefore probably mainly of Upper Jurassic age, but parts of the batholith may be of later age.' Dolmage (1926, p. 161), in describing the Tatla-Bella Coola area, writes: 'In Taseko Lake district what appears to be the main Coast Range batholith cuts a thick series of coarse fragmental volcanic rocks in which the writer found plant remains, determined by E. W. Berry to be of Cretaceous age. *** This evidence proves that this part at least of the batholith is younger than the lowest Cretaceous, and the evidence found in Tatlayoko Lake, Taseko Lake, and Bridge River districts strongly suggests that much of the eastern part of the batholith is of postbasal Lower Cretaceous.' Cairnes (1924, pp. 71-77, 89-105) suggests that at the southeastern part of the batholith, on the eastern border, there are intrusions of two ages. Masses of intrusive rocks that cut probable Jurassic beds are reported by him to be overlain unconformably by beds of Lower Cretaceous age, and the Lower Cretaceous beds are in turn cut by intrusions of pre-Tertiary age. On Vancouver Island the Mesozoic intrusive rocks are known definitely to be older than Upper Cretaceous."

In summary it may be said that in southeastern Alaska all indications are that the intrusives of the Coast Range batholith may be lower Cretaceous in age, but that on the east side of the batholith in Canada, the indications point to both an Upper Jurassic and Lower Cretaceous age.

HORNBLENDITE

General Features

Hornblendite occurs only in a single sill that crops out along the Gastineau Channel shore of Douglas Island. It forms the hanging-wall of some of the Treadwell ore deposits. It is about 3 miles long and averages about 250 feet thick, although in one place it attains a thickness of as much as 700 feet.

Strictly speaking the rock is a hornblende diorite, although in places, particularly near its southeast end, it contains mostly hornblende, and is properly termed a hornblendite. Because it was exposed in the Treadwell mines where it is truly a hornblendite, that term has locally been applied to the entire sill.

Is the hornblende at Treadwell ig. or meta? If meta then ore dep @ meta temps.

The texture ranges from coarse crystals, 2 and 3 inches long, to fine-grained schistose material. Hornblende is the most prominent mineral; in places augite attains secondary importance, and in other places oligoclase attains secondary importance. The hornblende is dark green and secondary after augite. Magnetitie is a common accessory and at places forms as much as 20 per cent of the rock. Titanite and apatite are other accessories.

The schistose appearance of much of the rock indicates that it was intruded prior to the regional metamorphism of the Coast Range orogeny.

Or is metamorphic

META-GABBRO SILLS

Distribution and Character

Meta-gabbro sills are confined almost exclusively to the Perseverance slate formation, although a few have been recognized in the underlying Gastineau volcanic group. Two principal types of rock, both included under the term meta-gabbro, are recognized, namely "brown" and "green." The brown meta-gabbro is a hydrothermally altered phase of the green meta-gabbro, and is invariably associated with quartz veins and ore shoots. The relationship of brown to green meta-gabbro is discussed elsewhere in this report under the heading "wall-rock alteration."

The meta-gabbro sills may be equally abundant within the Gastineau volcanic group as in the Perseverance slate, but if so they have not been recognized. Their outward appearance is so similar to most of the rock assemblage of the Gastineau volcanic group that recognition would be extremely difficult.

In general the meta-gabbro bodies have a sill-like shape ranging from a few inches thick and two or three feetlong to large masses a thousand feet thick at the center and whose projections extend for at least a mile away from the center.

The green meta-gabbro is typically a medium to coarse grained amphibolite consisting of bladed crystals of green hornblende in a less conspicuous groundmass of granular plagioclase. The rock is typically schistose, except where it is converted to brown meta-gabbro and the schistosity is destroy by the mineralogical changes.

As the prefix "meta" implies the gabbro sills have undergone metamorphism from an original rock presumed to have been a gabbro to the green schistose meta-gabbro or amphibolite. The metamorphism is presumed to be part of the same regional dynamic metamorphism that was caused by the intrusion of the Coast Range batholith.

Relation to other formations

The meta-gabbro sills were thought by some not to be intrusive at all, but instead to be lava flows laid down during sedimentation of the Perseverance slate. At most places the walls of the meta-gabbro bodies are parallel to the cleavage and bedding of the enclosing slates. At a few places, however, the intrusive nature of the meta-gabbro sills is readily apparent. Some of the meta-gabbro bodies, instead of being sill-like, as is the general case, are irregular, jagged, necks and plugs corresponding to no readily-described shape. These bodies cut across bedding and are clearly intrusive. At a few places, particularly near the ends of sills the slates are crumpled and close folded from microscope size to folds 6 or 8 inches in wave-length, indicating that the enclosing slates were plastic at time of intrusion. At still other places thin (one-fourth to 2 inches wide) sheets of meta-gabbro interfinger with equally thin bands of slate. Contact effects, other than the crumpling at the ends of bodies, are generally lacking. At most only a selvage 2 or 3 inches thick of hornfels surrounds the meta-gabbro bodies; at many places this selvage is lacking. Thus, the evidence of the intrusive nature of the meta-gabbro bodies is meager, but what evidence there is is incontrovertable and indicates that the meta-gabbro bodies are intrusive.

Except for a few rare cases inclusions of Perseverance slate are not found within the meta-gabbro bodies. The meta-gabbro bodies apparently have shoved their way into the Perseverance slate, pushing aside and crumpling the country rock.

The meta-gabbro bodies are spatially closely related to the gold deposits of the Alaska-Juneau lode system. Most of the ore bodies and ore shoots are to be found at the end or prong of a meta-gabbro body, in both the meta-gabbro and the surrounding slate. No ore shoots are found in the massive portions of meta-gabbro.

Lithology

Green meta-gabbro: The typical green meta-gabbro is a medium to coarse-grained, hard, schistose amphibolite consisting of green amphibole in a groundmass of plagioclase. The schistose structure is due to a crude parallelism of the bladed amphibole crystals.

The typical green meta-gabbro consists of about 50 per cent of dark green anhedral hornblende crystals poikolitically enclosing small anhedral grains of quartz in such a manner as to indicate that during metamorphism the hornblende crystals enveloped some of the quartz crystals. The hornblende of the green meta-gabbro is pargasite, a variety of hornblende slightly lower in iron content than most hornblende.

The material interstitial to hornblende is fine-grained quartz, plagioclase, and zoisite with the accessories magnetite and apatite. Apatite is associated with quartz and zoisite whereas magnetite is invariably either within hornblende or adjacent to it. The plagioclase is untwinned and can be distinguished from quartz on the basis of refractive index. The index of refraction indicates the plagioclase is andesine.

Brown meta-gabbro: Brown meta-gabbro is the results of the action on green meta-gabbro of hydrothermal solutions that emanated from quartz veins. The processes involved in the change from green to brown meta-gabbro are discussed under the heading "wall-rock alteration" elsewhere in this report.

Brown meta-gabbro is composed almost entirely of quartz, brown biotite and chlorite. Biotite is the most conspicuous mineral and is responsible for the rusty brown appearance of the outcrop and the bronzy tone when freshly broken. Brown meta-gabbro characteristically is non-schistose, in spite of the fact that green meta-gabbro from which it was derived is schistose. Apparently the biotite did not crystallize under conditions of differential pressure.

Age

The meta-gabbro sills are believed to be of igneous origin, and to have been intruded subsequent to the deposition of the Perseverance slate and Clark Peak schist, and prior to the intrusion of the Coast Range batholith. The schistosity within the meta-gabbro bodies is thought to have been developed during the regional metamorphism attendant with the Coast Range orogeny. Thus the age of the meta-gabbro is somewhere between Upper Triassic and Upper Jurassic-Lower Cretaceous.

ALBITE-MICA SCHIST

General Features

The rocks of this type occur in large bodies in two places. One of the places is in the Perseverance ground on the northwest slope of the Gastineau Peak-Mt. Roberts-Sheep Mountain divide where one large sill and several smaller sills crop out on the surface and are found underground. Theother place is on the southeast slope of Sheep Mountain where a single large sill crops out.

The largest sill in the Perseverance ground is about 3,200 feet long and 100 to 200 feet wide. The sill on the southeast flank of Sheep Mountain is nearly 4,000 feet long and tapers from 800 feet wide near its southeast end to about 100 feet wide at its northwest end.

The albite-mica schist bodies are massively schistose, coarse-grained intrusive rocks composed of about 70 per cent of albite, 20 per cent of mica (both biotite and muscovite), and 10 per cent of accessory minerals magnetite, rutile, apatite, and tourmaline.

The rock has been thoroughly albitized by pervading solutions, some of which have affected the surrounding sediments so that they too are albitized and are difficultly distinguished from the near by igneous rock.

The albite-mica schist sills are found only within the Perseverance slate formation. They possibly occur within other formations, but it is doubtful if they do, for the albite-mica schist is a distinct and easily recognized rock type. The outcrop pattern of the albite-mica schist bodies indicate them to be intrusive rocks. Their crude schistosity indicates that they were intruded prior or during the regional metamorphism and orogeny that took place in southeastern Alaska during late Jurassic or early Cretaceous time.

Lithology

The typical albite-mica schist is a schistose rock composed of about 70 per cent of albite, 20 per cent of mica (both muscovite and biotite), and 10 per cent of accessory minerals.

Albite occurs as lenticular masses about 1/16 of an inch across that have minute dust-like inclusions paralleling the long axis of the albite lenticles. The whole appearance of the albite is of having been squeezed or to have crystallized under conditions of differential pressure. Albite was the last mineral to crystallize and includes the dust particles previously crystallized. Considerable fine sericite is scattered within the albite and is oriented parallel to the schistosity.

The mica minerals, biotite and muscovite, occurs in about equal amounts in the albite-mica schist. They occur as small plates randomly oriented within the rock and quite obviously crystallized prior to albite as albite envelopes the smaller mica crystals.

The accessory minerals are rutile, apatite, magnetite, pyrrhotite, tourmaline, zoisite, calcite, and quartz. Not all thin sections of the rock show all of these accessory minerals; it is presumed that they are not universally present throughout the albite-mica schist. Tourmaline, zoisite, calcite, and quartz are obviously secondary minerals formed and introduced with the solutions that albitized the rock. The magnetite occurrence is somewhat unusual as it occurs as tiny needles oriented throughout the rock. Quartz occurs as tiny veinlets which cut across the schistosity of the rock. Much of the albite-mica schist is not silicified at all.

DIORITE PORPHYRY - Post kinematic

General Features

Diorite-porphyry sills crop out within the Treadwell slate on Douglas Island and to the northwest in the Eagle River region. They occur as long, thin sills parallel to the regional cleavage and bedding. They may be as much as several miles long and several hundred feet thick.

The diorite porphyry sills are said to intrude the Treadwell ore bodies and hence be younger than those deposits; others have said that the Treadwell deposits merely represent a mineralized phase of the diorite porphyry. It is not within the scope of this report to discuss this feature. However, it should be pointed out that the diorite porphyry is not foliated and has noticeably obliterated the slaty cleavage of the enclosing rocks. These two facts adequately demonstrate that the diorite porphyry sills are younger than the regional metamorphism associated with the Coast Range orogeny.

The diorite porphyry is fine-grained and distinctly porphyritic. The phenocrysts are oligoclase and hornblende, with the former dominating. The groundmass is fine-grained and generally light-colored. Chill-phases as much as 2 or 3 feet wide are distinct and common; they are dark colored, and in places contain glassy quartz phenocrysts.

The sills are easily recognized for they have a characteristic appearance due to their light color and lack of metamorphism.

ALASKITE AND BASALTIC DIKES AND SILLS

General Features

These two contrasting types of intrusives are the youngest known consolidated rocks in the Juneau area and are the only intrusives that exhibit any tendency to cut across regional structures. None of them has been metamorphosed nor mineralized by the gold-bearing solutions in spite of the fact that many of them are known in both the Treadwell and Alaska-Juneau lode systems. The several basaltic dikes in the Alaska-Juneau mine cut across Silver Bow fault and have not been offset by the movement along the fault.

Dikes and sills of these two contrasting types, particularly of the basaltic type are widespread throughout southeastern Alaska, although not particularly abundant. On the south end of Admiralty Island basaltic dikes cut Eocene rocks, and because of this fact it is concluded that all basaltic dikes in southeastern Alaska are Tertiary. The writer knows of no evidence to the contrary.

Spencer (1906, p. 19) has described the general lithology of the basaltic dikes, as follows:

"Several small dikes of dark-colored rock crosscutting the various formations have been noted in the vicinity of Juneau. In the workings of the Alaska-Juneau mine in Gold Creek three parallel dikes of diabase averaging about 6 feet in width were noted. The rock has a fine-grained diabasic texture and consists of greatly decomposed feldspar, probably labradorite, together with basaltic hornblende partly altered to uralite. Magnetite occurs in disseminated grains."

Only one Alaskite sill has been found in the immediate vicinity of the Alaska-Juneau lode system. This occurs as a long sill extending at least from Gold Creek to Salmon Creek. It is about 5 feet wide. It is nearly white in color and consists of a felsic groundmass with phenocrysts of quartz and muscovite. It is virtually void of dark minerals.

UNCONSOLIDATED ROCKS

Throughout the Juneau area are many different types of unconsolidated surface materials of small areal extent. Recent glaciation has removed most of the products of rock weathering and without exception all of the present surface material is the product of glacial conditions or of products deposited since glaciation. All material formed by rock decay since Cretaceous time and prior to the ice age, has been removed or reworked by glacial ice.

The unconsolidated rock deposits in the Juneau area may be grouped into four main groups: glacial deposits, beach deposits, alluvial deposits, and landslide deposits. In some cases it is not possible to differentiate the particular type of deposit. Beach deposits, for example, may be readily confused with glacial till or landslide material.

No attempt has been made to outline the many areas of unconsolidated rocks on the accompanying geologic map. Only the largest areas are depicted.

Glacial Deposits

In the Juneau area the glacial deposits consist only of lateral and ground moraine (till). At nearby Mendenhall Glacier are numerous recessional moraines, but no where within the Juneau area are there recognizable recessional or terminal moraines. Types of glacial deposits other than ground moraine may be present within the area shown on the geologic map, but if so they have not been recognized. Ground moraines is found only at altitudes below about one thousand feet and only on relatively flat areas. The lack of glacial moraine above about one thousand feet is caused by the steep slopes above this altitude on which it is impossible for morainal material to cling to the mountain sides. All of the ridge and mountain tops in the Juneau area were glaciated, but the most recent valley glaciers only attained an altitude of about 2,500 feet where they entered Gastineau Channel. Consequently the ridge and mountain tops above the valley glaciers were exposed above the ice for a much greater time than were the valley slopes and bottoms. Morainal deposits that may have been present on the ridge and mountain tops have long since been eroded away.

The typical ground and lateral morainal material consists of boulders and cobbles, some rounded and some not, embedded in a blue-gray glacial flour. It is completely unsorted. On the basis of physical characters alone it is difficult to distinguish moraine from bench deposits and some landslide material.

Beach deposits

Beach deposits are widespread and a most conspicuous feature in the Juneau area. Present-day beaches extend all along Gastineau Channel, being several hundred feet wide in the northwest part of the area and only a few tens of feet wide in the southeast part.

Elevated beaches, some as much as 500 feet above present sea level, have been found in the Gastineau Channel area. The most conspicuous elevated beach is about 50 feet above sea level and is nearly everywhere present. The reader is referred to a report by Twenhofel (1952) for a description of elevated beaches in the Juneau area.

The material of both the elevated and present-day beaches is derived from two cources; namely the sea-cliff and glacial moraine. Glacial moraine is by far the principal contributor and virtually all of the beaches can only be distinguished from glacial moraine by the presence of marine shells embedded in glacial flour. The shells are all very well preserved and are identical with species living today in the coastal waters.

Beach deposits are generally unstratified and appear to have been but little reworked by the sea. Only the present-day beach is a prominent topographic feature.

Alluvial deposits

Alluvial deposits of sand, silt, and gravel are widely distributed along the valley bottoms of the principal streams, such as Gold, Salmon, and Sheep creeks, and to a lesser extent in the valley bottoms of the streams on Douglas Island. The most extensive alluvial deposits are found in the form of deltas at the mouth of the larger streams and in the several basins of the stream valleys.

The deltaic deposits are the largest of the alluvial deposits and some comprise deposits containing millions of cubic yards of material. The largest delta deposits in the area shown on plate are at the mouths of Gold and Salmon creeks. At both of these localities are elevated as well as present-day deltas. The elevated deltas attain a maximum altitude of about 200 feet and are deeply eroded and only remnants remain. The materials eroded from the uplifted deltas now comprise much of the debris in the present-day deltas.

The deltas of Gold and Salmon creeks are composed of well-washed and well-sorted sands and gravels. The uplifted deltas constitute a valuable source of sand and gravel for construction and road building purposes in the local community.

All of the so-called basins in the area have a bottom fill of gravel and sand. The basins are nearly level areas in the stream profile and are characteristic of all but the larger streams of southeastern Alaska. In addition to the stream deposited materials in the basin there is considerable landslide material from the adjacent slopes. The gravels of the basins on Gold Creek have all been worked in the past as placer deposits, but only in Silver Bow Basin did the gravels contain sufficient gold to be worked successfully. This type of alluvial deposit is made possible by the presence of rock basins formed by the glacier that formerly occupied each valley tributary to Gastineau Channel.

Landslide deposits

Landslides are prominent features in the Juneau area. They occur on steep slopes particularly in the spring and fall of the year when the ground becomes saturated with water. Prominent soars mar the steep slopes where past slides have cascaded down, removing all vegetation from their path.

Slides are the main agent of rock transport and erosion in the Juneau area today. They contain vegetation, snow, water, soil, morainal material, and blocks of bedrock loosened by freezing and thawing along fractures in the bedrock.

Landslides contribute most of the detrital material to the present-day streams, and are the source for most of the material now deposited in the alluvial deposits.

SUMMARY OF AGE RELATIONSHIPS

The age of the rocks in the Juneau area has been discussed and speculated on by several writers. The evidence bearing on the age of the rocks is very meagre and inconclusive.

The only fossils found in any of the rocks of the Juneau area were found by Spencer and Eakin in 1916 (see page 60). They were collected from a narrow slate band within the Gastineau volcanic group near their northeastern edge and were identified as Upper Triassic. If, as seems reasonable to presume, the entire assemblage of volcanic material represented by the Gastineau volcanic group accumulated during a relatively short time, geologically speaking, then it follows that the entire Gastineau group is Upper Triassic in age.

Because fossils have not been found in any of the other rocks in the Juneau area, all inferences as to their age much be based on correlations with similar rocks of neighboring localities. However, correlations based on similar lithology are hazardous and must be done with care, particularly with the rocks of southeastern Alaska, which are so similar in lithology and yet are widely different in age.

The Wrights (1908, p. 55) report that in 1905 E. M. Kindle found specimens of Productus aff. P. gruenewaldti Krot. in altered limestone near the base of a slate-greenstone band at Taku Harbor 25 miles southeast of Juneau. These specimens indicate a Pennsylvanian (the Upper Carboniferous of the Wrights) age for the rocks at this point. Spencer (1906, pp. 9-11), on the basis of fossils found at Taku Harbor, regarded all of the rocks in the Juneau area as Paleozoic. However, the later discovery of Triassic fossils in the Gastineau group invalidates, in part at least, Spencer's correlation. However, until the stratigraphic and structural relationships of the limestone, from which the Pennsylvanian fossils were collected, are determined with respect to the rocks equivalent to those at Juneau, the assignment of Pennsylvanian age to any of the rocks in the Juneau area must be regarded merely as a possibility and not as a probability. At present it is not known if any of the Pennsylvanian rocks extend north of Taku Inlet. Knopf (1912, p. 18) has described the limestone at Taku Harbor as follows:

"The fossiliferous beds consist of bluish-gray to nearly black marbles, interstratified with welded limestone breccias. The calcareous rocks are associated with phyllite and green schists, showing an abundant development of micaceous minerals. A few miles farther south, at Limestone Inlet, are a series of surface volcanic rocks - amygdaloids and breccias - which are roughly schitose and show finely disseminated biotite on their foliation planes. Notable among these is a porphyry showing prominent tabular phenocrysts of feldspar; examined microscopically, they prove to be microcline microperthite phenocrysts embedded in a trachytoidal groundmass of albite laths interspersed with considerable flaky biotite."

Knopf concludes that the known Pennsylvanian strata are much more highly metamorphosed and different in lithologic character than any of the slate-greenstone rocks of the Juneau area and consequently the Carboniferous strata at Taku Harbor do not extend to Juneau. The writer takes exception to Knopf's reasoning that the difference in metamorphism and lithologic character of the rocks in the two localities are adequate evidence for presuming that the Pennsylvanian rocks do not extend to Juneau. Degree of metamorphism may be a function of age of the rocks in question, but it also may be a function of the nearness and susceptibility of the particular rock to the forces and processes producing the metamorphism. Thus the alleged more highly metamorphic character of the Taku Harbor rocks may be the result of these rocks occupying a position in relation to the Coast Range batholith that was more favorable for metamorphism. Although the author has not seen the rocks in question at Taku Harbor and Limestone Inlet, he thinks there is considerable similarity between parts of the Gastineau volcanic group and the volcanics dexribed by Knopf at Limestone Inlet. The author does not wish to imply that the Pennsylvanian rocks at Taku Harbor do extend to Juneau - he merely wishes to point out that the question of whether there are Paleozoic rocks in the Juneau area is still unanswered.

The only other nearby locality where fossils have been found is at Berners Bay. Knopf (1911, pp. 14-17) collected fossils plants from exposures of the "Berners formation" on the east side of Berners Bay just north of Sawmill Cove. His description of the fossil-bearing rocks is as follows:

"The rocks *** consist of an interdigitating series of thick lenses of graywacke and argillite standing on edge. The graywackes show cross-bedding and the agillites are ripple-marked. *** Leaf-bearing beds seem to be scarce, and the best fossils collected were obtained from a roughly schistose argillite which was gashed by quartz veinlets."

Knopf submitted the plant fossils to F. W. Knowlton of the Geological Survey, who reported on them as follows:

(Knopf, 1911, p. 17)

"This material is very difficult to study, for practically all traces of nervation are absent and dependence must be placed on outline, which has obviously been more or less modified by pressure. With these limitations in mind, I think I have been able to demonstrate the presence of Taeniopteris, Asplenium or Dicksonia, Thinnfeldia (?) and possibly another fernsomething like Dryopteris.

"The choice appears to lie between Jurassic and Lower Cretaceous, and if what has been supposed to be Taeniopteris is really such the odds favor the former. I have not found anything that can be identified as a dicotyledon, which also is favorable to the probability of its being Jurassic. Although the evidence adduced is not very strong and the identifications are tentative, it seems most probable that they are Jurassic in age."

At a later date Knowlton further remarked upon the same collection of fossil plants collected by Knopf:

(Martin, 1926, pp. 259-260)

"The specimens are very small, almost devoid of nervation, and obviously more or less distorted by pressure. The specimens I said might be Taeniopteris have nothing but the midrib preserved or possible fain traces of lateral nerves. Without some positive notion of the lateral nerves it is impossible to distinguish this genus from Pterophyllum, Nilssonia, etc. It is not of much value as it stands.

"Another specimen, identified in the first report as possibly Asplenium or Dicksonia, with wider experience I should not incline to call Onychiopsis, close to an perhaps identical with O. mantelli, but it is obscure as to outline and without a trace of nervation. I therefore hesitate to say it is Onychiopsis, though it certainly does look like it.

"The scrap referred to as Thinnfeldia (?) looks also like some forms of Thyrsopteris, but it is without nervation and hence very uncertain.

"There are some fragments that suggest Cladophlebia, but I can't be certain about them.

"So much for the things themselves: What can be said with reasonable safety regarding their age indications? Obviously, if we can not determine the genera, we are not in a position to interpret their stratigraphic value with accuracy. However, I will go so far as to say that they are, in my opinion undoubtedly Mesozoic. There is not a thing that could be as old as the Paleozoic. If I have been anywhere near correct in identifying them, the choice must still be between Lower Cretaceous and Upper Jurassic. They might well enough be Upper Jurassic, but I do not think they can be older than Jurassic."

Some fossils were collected by Theodore Chapin from graywacke float near the wharf of the Jualin mine at Berners Bay. The following statement regarding them was made by G. H. Girty: (Martin, 1926, p. 260)

"15-ACh-310. Locality Jualin wharf, Berners Bay. Graywacke float. It is not believed that this rock traveled far, for it is similar to the rock in place along the coast - the graywacke of the 'Berners formation.' This collection contains a few fossils in a fragmentary condition, as follows:

"Some impressions that suggest either graptolites or fenestelloid Bryozoa. Mr. Kirk showed these fossils to Mr. Ulrich, who states that they belong to the genus Pinnatopora (one of the Fenestellidae). If the fossils are graptolites the age of this lot would be Cambrian or Ordovician. If they belong to the genus Pinnatopora the age would be Devonian or Carboniferous.

"Besides these there are impressions that might be external molds of the dorsal valve of a Derbya or Schuchertella, another impression that suggest some species of Oviculipecten, and part of a spirally ribbed coiled shell that might be either a cephalopod or a gastropod, according to the character of the missing parts of the fossil.

"So far as I can see you have a free hand in making this lot anything in the Paleozoic except Cambrian, with the probabilities, however, in favor of Carboniferous (Mississippian(?))."

The "Berners formation" in the Eagle River region has been since subdivided by the author into several mapable units - namely, the Treadwell slate formation and the Gastineau volcanic group - and hence "Berners formation" has outlived its usefullness as a stratigraphic term. The fossil locality noted by Knopf north of Sawmill Cove at Berners Bay has been mapped as the northwesterly extension of the Treadwell slate, and, consequently, if Knowlton's determinations are correct, the Treadwell slate is Mesozoic and possibly Jurassic.

The determination that the fossils collected by Chapin at the Jualin wharf are Paleozoic and probably Carboniferous (Mississippian (?)), coupled with the existence of Carboniferous (Pennsylvanian) rocks at Taku Harbor, is indicative of the presence of Carboniferous rocks within the Juneau area, but until such time as the rocks at the two fossil localities mentioned are traced into the Juneau area, the presence of Carboniferous rocks in the Juneau area cannot be substantiated.

Thus on the basis of paleontologic evidence alone one is led to the conclusion that the Gastineau volcanic group is Upper Triassic and that the Treadwell slate is Mesozoic and possibly Jurassic.

As described in this report until the section on "Geologic structure" the author believes all of the rocks from the Douglas volcanic group to the Clark Peak schist were deposited without a major stratigraphic break. The whole series is a single conformable sequence representing more or less continuous deposition. All structural evidence leads to the conclusion that the sedimentary and volcanic rocks of the Juneau area are right side up - not overturned as was postulated by Eakin (1922) and Martin (1926, p. 93).

Because the present author differs with previously published reports on the structure of the rocks in the Juneau area, it seems pertinent at this time to inquire as to the basis for earlier statements regarding the structure and stratigraphic sequence of the rocks of the Juneau area. The structural facts are presented in the section on "Geologic structure" and the paleontologic facts were presented on the previous pages. The facts themselves are in no sense contradictory - they all indicate or permit the conclusion that the sequence of rocks in the Juneau area is conformable without stratigraphic breaks and is in its normal stratigraphic position with the oldest rocks on the southwest and the youngest on the northeast.

What then is the evidence upon which Eakin and Martin based their conclusions that the section at Juneau is overturned? Eakin based his conclusion on the fact that Upper Triassic fossils were found in the Gastineau volcanic group and that Jurassic-Cretaceous fossils were found in the "Berners formation" and at Pybus Bay on Admiralty Island. The two latter locations lie westward of the projected strike of the Gastineau formation and consequently their position indicates that the Juneau section is overturned. Recent mapping by the author has demonstrated that the "Berners formation" is the northwesterly extension of the Treadwell slate and this would tend to substantiate Eakin's conclusions. However, the fossils collected by Knopf from the "Berners formation" were only tentatively assigned to the Jurassic and the fossils collected by Chapin from the "Berners formation" were assigned to the Paleozoic. Actually both collections of fossils were very poorly preserved and their age assignments are most uncertain; it must be admitted that these two fossil collections are not sufficient evidence to prove to disprove if the rock section at Juneau is overturned or not.

The fossils at Pybus Bay were collected from slates and conglomerates by Wright and were reported on by T. W. Stanton as follows:

(Wright, 1906, p. 144)

> "The specimens of *Aucella* from Pybus Bay, Admiralty Island, are apparently referable to species that in California and adjacent States are characteristic of the Lower Cretaceous *Aucella piochii* occurring in a lower zone than *Aucella crassiocollis*. The Alaskan specimens probably also came from the Lower Cretaceous, although strict correlation is rendered somewhat hazardous by the fact that the genus *Aucella* with similar specific forms ranges down into the Upper Jurassic."

Thus there is little doubt that slate and conglomerate beds at Pybus Bay are either Lower Cretaceous or Upper Jurassic, but there is a great deal of doubt if these rocks are correlative with any of the rocks in the Juneau area. The slates and conglomerates were correlated by Wright (1906, pp. 143-144) with the slates and graywackes in Seymour Canal, but this correlation is based only on lithology and until the structure of the southern part of Admiralty Island is deciphered this correlation is to be regarded as only tentative. As a matter of fact the Pybus Bay rocks lie west of the strike of the Seymour Canal rocks and it is extremely doubtful if the two groups of rocks are equivalent.

Thus upon close analysis it is found that the conclusion that the section at Juneau is overturned is based on very inconclusive evidence and in the light of the structural evidence indicating that the section is right side up, one must conclude that Eakin's (1922) conclusion is in error.

Martin (1926, p. 93) based his writings of the Juneau area entirely upon Eakin's work and consequently also postulated that the Juneau section is overturned. He presented no new evidence to substantiate Eakin's conclusion.

METAMORPHISM

GENERAL FEATURES

With the exception of the unconsolidated rocks, the Tertiary (?) dikes and sills, and the diorite porphyry sills on Douglas Island, all of the rocks of the Juneau area are metamorphosed. In the following paragraphs the writer excludes any discussion of wall-rock alteration related to the mineral deposits, which though a metamorphic process, is properly discussed in relationship to the mineral deposits.

At least two phases of metamorphism are present within the Juneau area, although the distinction between the two types is far from clear. A regional dynamic metamorphism has affected the whole area, in face has affected almost all of the rocks of southeastern Alaska. It has imparted to all but the massive rocks a well-developed cleavage or schistosity which was produced by a preferred orientation of sericite and chlorite minerals. The metamorphic rank is rarely greater than that necessary to produce chlorite and sericite. Limeation, produced as a consequence of dynamic metamorphism, is not conspicuous nor is it everywhere present.

Adjacent to the Coast Range batholith, and affecting the border of the batholith, but also affecting the enclosing rocks to a much greater areal extent, is a zone of thermal metamorphism about one-half to two miles wide that is superimposed upon the dynamic metamorphism mentioned above. Higher temperature metamorphic minerals such as garnet, biotite, feldspar, and amphibole, are present in this zone than are present in the rocks farther away from the batholith.

The zone of thermal metamorphism is thought to be caused by the main part of the Coast Range batholith inasmuch as the zone encompasses only the outlying sills and borders of the batholith and the adjacent sediments of the Clark Peak schist. The regional dynamic metamorphism is os widespread that it is difficult to attribute it to any specific cause. About all that can be said is that it has affected all rocks younger than the main Coast Range batholith, including its outlying sills and border, and therefore, must be related to the Coast Range orogeny.

Study and analysis of the metamorphic effects in the Juneau area is difficult because the zone of thermal metamorphism is nearly parallel to the trend of the various groups of rocks. Because of the general edging-over to the west of the Coast Range batholith toward the north, the zone of thermal metamorphism likewise transgresses formational boundaries. Thus in a general way it is possible to determine the metamorphic effects on a given rock unit by comparing the rock unit on the southeast part of the monocline where it is farther from the batholith than at the northwest part where it may be adjacent to the batholith. However, possible original lithologic changes along the strike of the formation renders such an analysis difficult to make.

THERMAL METAMORPHISM

In the Juneau area only the Clark Peak schist, the outlying sills of the Coast Range batholith, and the albite-mica schist, are thermally metamorphosed. The effects of thermal metamorphism overshadow the effects of dynamic metamorphism, but the rocks still retain their well-developed cleavage and schistosity, and locally a crude lineation. All of the rocks are recrystallized and a few of the original minerals still persist. In spite of extensive recrystallization the original bedding in the sediments is still retained and is probably as distinct as originally. This fact indicates that little or no new material from outside sources was added during metamorphism. An exception are parts of the albite-mica schist bodies which have been extensively permeated with albite- and quartz-bearing solutions.

The effects of recrystallization are strikingly revealed by the presence of oriented biotite and muscovite crystals, garnet, chlorite, amphibole, clinozoisite, untwinned plagioclase, kyanite, epidote, and recrystallized quartz. The few original limestone beds are now completely recrystallized to marble.

DYNAMIC METAMORPHISM.

Dynamic metamorphism has produced a well-defined schistosity and cleavage in all but the massive rocks and particularly in the tuffs and black slates. In addition to cleavage, which is nearly everywhere parallel to the bedding, dynamic metamorphism has produced several joint systems and one direction of lineation. These features are more fully discussed in this report under "Geologic structure."

The Perseverance and Treadwell slates were originally deposited as fine-grained muds rich in organic matter. As a consequence of dynamic metamorphism they were compacted, subjected to differential stresses and probably elevated

AGE OF METAMORPHISM

The cleavage, joints, lineation, and mineralogical changes associated with the widespread dynamic metamorphism undoubtedly had a common origin and were produced at the same time. The thermal metamorphism was either contemporaneous with, or subsequent to, the dynamic metamorphism. The relationships are obscure. Because the position of the effects of thermal metamorphism are adjacent to the Coast Range batholith it is assumed that the batholith provided the necessary heat, and, therefore, that thermal metamorphism is contemporaneous with the main intrusion of the batholith. The dynamic metamorphism is believed to be at least slightly prior to the thermal metamorphism for the thermal appears to mask the dynamic. Thus the dynamic metamorphism is thought to predate all but the earliest stages of the Coast Range intrusion. It is believed that the main portion of the Coast Range batholith was injected subsequent to dynamic metamorphism for the batholith is not foliated nor is it well jointed. However, the dynamic metamorphism obviously was caused by the Coast Range orogeny, for the metamorphism affects all rocks earlier in age than the main Coast Range batholith.

Thus in recapitulation, the events concerning metamorphism start in Upper in temperature. The carbon of the organic matter was converted to graphite and much of the argillaceous material was recrystallized to sericite with a little chlorite. The development of sericite oriented parallel to the bedding is responsible for the excellent cleavage of these rocks.

The tuff beds of the Gastineau volcanic group was affected by dynamic metamorphism just as much as the slate beds. They all have a fine slaty cleavage parallel to the bedding. The ferromagnesian and argillaceous minerals were all converted to chlorite and in some cases to actinolite, thus imparting to all these rocks a light green color.

The lava rocks of the Gastineau and Douglas Island volcanic groups are the least affected by dynamic metamorphism of any of the rocks. Apparently their massiveness resisted dynamic stresses and only locally has cleavage developed in them. They are jointed, but not nearly as much as are the finer-grained bedded rocks. Recrystallized minerals, developed as a consequence of dynamic metamorphism, are chlorite, sericite, calcite, and epidote.

All of the recrystallized minerals developed by dynamic metamorphism are characteristic of low-grade rank and, therefore, indicate that temperatures of the rocks affected were comparatively low.

Jurassic-Lower Cretaceous time with the beginning of the Coast Range orogeny (the time of greatest stress) and the consequent development of the dynamic metamorphic effects. This stage was followed by a time of waning stress and pressures and the intrusion of the main batholith and consequent thermal metamorphic effects.

GEOLOGIC STRUCTURE

GENERAL FEATURES

The Alaska-Juneau lode system lies within a belt of stratified metamorphic rocks believed to be Mesozoic in age and probably of Triassic and Jurassic age. This group of rocks extends along the mainland coast of southeastern Alaska from Berners Bay southeasterly to at least Port Houghton, a total distance of about 120 miles, and the belt may extend over a much greater distance. On the northeast this belt of rocks is bounded by the Coast Range batholith. There is no mapping done that would enable the southwest border of this belt to be determined, other than to say it may extend as far west as Chatham Strait.

Throughout the Mesozoic belt along the mainland the rocks strike northwest-southeast and dip from 30 to 70 degrees northwest. Both bedding and schistosity are parallel throughout the belt. The mainland Mesozoic belt, in-so-far-as now known, is a monocline that dips beneath the Coast Range batholith. Buddington and Chapin (1929, pp. 298-299) describe the mainland belt of Mesozoic rocks to be part of a synclinorium named by them the "Juneau Synclinorium." According to them the southwest limb of the synclinorium lay west of Seymour Canal on Admiralty Island. They believe the major structure to be synclinal rather than anticlinal on the basis of fossil evidence that is far from conclusive. The synclinorium postulated by Buddington and Chapin requires the rocks in the immediate vicinity of Juneau to be overturned, a supposition believed to be incorrect in the light of structural data presented herein.

In an earlier paper Martin (1926, p. 94-95) using data presented by Eakin (1922) also assumed the entire rock section of the Juneau area to be overturned. Their evidence, which is more fully presented in this report in the section "summary of age relationships," is based on correlation of the Juneau rocks with similar lithologic units elsewhere in southeastern Alaska.

Evidence collected by the writer indicates the rocks of the Juneau area to be right side up. Within the lavas of the Gastineau volcanic group, on the north shore of Taku Inlet, pillow lavas are well exposed. The pillows have their convex side facing the northeast and their flat or bottom side facing southwest. Similarly, pillow lavas in the Douglas Island volcanic group that are so abundantly and well exposed along the east shore of Lynn Canal between Yankee Cove and the south shore of Berners Bay, have their convex surfaces facing to the northeast. Thus it may be safely concluded that both of these volcanic groups are right side up.

Less conclusive, but never-the-less indicative, evidence was noted at several localities where the slates were seemingly converted to hornfels by the Douglas Island volcanics that rested against the slates. In all cases the volcanic rocks were found to lie to the northeast of the hornfels, thus indicating that the hornfels-slate was deposited prior to the volcanics, and further indicating that the section is right side up.

It might be expected that cross-bedding and ripple marks would be abundant within some of the graywacke of the Treadwell formation, but in spire of diligent search only one questionable wave-ripple mark was found and several very poor indications of cross-bedding were seen. These occurrences, admittedly poor as evidence, all indicated the tops of the beds to lie to the northeast.

None of the other criteria often usable for determining tops from bottom of beds and flows was found.

Therefore, on the basis of the evidence presented above, and in spite of previous assertions to the contrary, the writer firmly believes that the monoclinal structure of the Juneau area is right side up, and believes the oldest rocks to be the Douglas Island volcanic group and the youngest of the sedimentary and volcanic rocks to be the Clark Peak schist.

STRUCTURAL TRENDS

Contacts and Beddings

The general strike of all rocks within the Juneau area is N.47°W. and the dips average 72 degrees northeast. There are, however, many variations in strike from N.5°W. to N. 85°W. and variation in dip from 20 degrees northeast to vertical. An equal-area plot of the altitude of 218 readings of dip and strike of the bedding (cleavage) is shown in figure 4.

In the lode system itself the bedding (cleavage) strikes N.50°W. and dips 55 degrees northeast (see fig. 5). It is to be noted that the altitude of the bedding of the lode system is slightly different from the general altitude of the bedding throughout the Juneau area. No particular significance is attached to this difference as the observations within the lode system fall within the range of variation of the readings for the whole area.

It is a matter of direct and repeated observation that the altitude of cleavage and bedding are parallel throghout the Juneau area except in those instances where the beds are dragged into small drag folds, rarely more than ten feet across. For all intents and purposes bedding and cleavage are identical.

Figures 4 and 5 illustrate a characteristic feature of the Juneau area and the lode system, namely that where the bedding (cleavage) swings westerly the dip becomes greater. This situation indicates that minor flexures occur on the monocline with their axes lying in the plane of the bedding and plunging steeply to the north, approximately parallel to axis "a" in figures 9 and 10.

All the sedimentary and metamorphic rocks in the Juneau area are conformable and the bedding and cleavage are parallel to the contacts between the formations. All intrusive rocks are generally concordant with the bedding, with the exception of the large sill near the top of Mt. Juneau; this is slightly cross-cutting with respect to the strike of the enclosing sediments, although its dip appears to be the same.

Folds

There are no major folds in the Juneau area. All observed folds are interpreted as minor drag folds caused by the slipping of beds on the northeast side upward with respect to beds on the southwest side. None of the folds is more than a few tens of feet across and most of them are only a few inches across. They are found only in thin bedded rocks that apparently served as the locus of adjustment between the more massive beds as they were tilted into their present position on the regional monocline.

The axial planes of the drag folds lie parallel to the bedding and cleavage of the rocks; consequently, the axes of the folds lie within the bedding and cleavage. On many slate cleavage surfaces is a rude lineation and corrugation which is parallel to the axes of the drag folds. Both lineation and axes of drag folds are plotted on figure 6. The maximum position is extremely well defined and illustrates the remarkable uniformity of both lineation and the axes of drag folds. Their position is within both the cleavage and an imaginary N.84°W. vertical plane. Within this plane the axes plunge 35 degrees to the east.

Joints

All of the rocks of the Juneau area are broken by numerous joints. They are best developed in the Perseverance slate and the Gastineau volcanic formation, although they are conspicuous in all types of pre-batholithic rocks. In the lode system the joints pre-date the introduction of the quartz veins for they do not cross the veins. The joints also pre-date the faulting as non of them crosses the faults.

In addition to cleavage, (which actually is a joint too), there are three well-defined joints. These are plotted on a spherical projection in figure 7. The most prominent set strikes N.30°E. and dips 76 degrees to the northwest. The next best developed set of joints strikes N.34°W. and dips 40 degrees to the southwest. It is approximately perpendicular to the cleavage (see figures 9 and 10). The third and most poorly developed set of joints strikes north-south and dips 45 degrees to the west. It too is approximately perpendicular to the cleavage. This set of joints is interpreted as a cross joint system because it lies perpendicular not only to the cleavage but also to the lineation and drag-fold axes. The other two sets of joints are referred to as joints 2 and 1 respectively.

The veins occupy a joint set that has not been distinguished except for the fact that it is filled with vein material. In other words the joint set now occupied by the veins of the lode is not apparent elsewhere other than in the lode system where it is filled with vein material. The veins (see fig. 8) strike N.36°W. and dip 78 degrees northeast.

<u>Mutual relationship of joints</u>. The actual geographic position of cleavage,

veings, and joints is shown in stereographic projection on figure 10 as solid-line arcs representing the traces of the various planes on the spherical projection. On this same figure are plotted the positions of the three standard, mutually perpendicular, axes of reference, namely "a," "b," and "c." The "b" axis coincides with the maximum position of lineation and drag-fold axes. It lies within the plane of the cleavage. The cleavage plane is considered to be the "ab" plane, a plane of shear. The "c" axis, of course, is perpendicular to the "ab" plane and lies within the plane of the cross joint; the "a" axis is perpendicular to both axes "a" and "c" and when plotted is found to be the intersection of the planes on the cross joint and the cleavage. The coincidence of axes "a" and "c," both lying within the plane of the cross joint thereby determines that said joint is a cross joint. It is to be noted that the planes of cleavage, cross joint, and vein intersect along the "c" axis, and that the planes of joints 1 and 2 approximately intersect along the "c" axis. By virtue of the fact that the plane of the cross joint is the "ac" plane, it is perpendicular to drag-fold axes, lineation, and cleavage.

On figure 10 all of the various planes are rotated about a north-south axis to a position 45 degrees to the west so that the plane of the cross joint is perpendicular to the plane of the illustration. The resultant rotated positions of the planes is shown as dashed-line arcs of the traces of the planes on the spherical projection. In the rotated position the trace of the cross joint becomes a straight north-south line representing a vertical plane that is a plane of symetry with respect to the rotated positions of the planes of cleavage and joints 1 and 2. The plane of the vein is not symmetrical with respect to the plane of the cross joint.

Because the planes of cleavage, cross joint, and joints 1 and 2 are all part of a system with a plane of symmetry coinciding with the plane of the cross joint, it is concluded that all of these planes are directly caused by the one set of stress; the same set that placed the rocks in their present position.

The plane of the vein occupies a somewhat anomolous situation with respect to the other joint planes. On one hand it appears not to belong with the other planes, as it is not part of the symmetry system. However, on the other hand it contains the "a" axis and, therefore, may belong to the system of the other planes. The data do not reveal which alternative is correct.

Relationship of joints to causative stress. In figure 9 an attempt is made to depict and relate the planes of cleavage and joints (except the plane of the vein) to a hypothetical, oriented strain allipsoid. The cleavage and contained "b" axis are oriented so that the plane of the cleavage is a shear plane of the strain ellipsoid and the "b" axis coincides with the "B" axis (intermediate) of the strain ellipsoid.

Figure 9 shows that the component of maximum stress is a north-south direction along the short axis, "C"-"C," of the strain ellipsoid. Therefore, it is postulated that the orogenic stresses which tilted the rocks to their present position during the Coast Range orogeny during the late Jurassic and early Cretaceous, had their component of maximum stress directed in a horizontal plane along a north-south direction.

Figure 9 shows that the component of maximum relief is axis "A"-"A," a line lying in a vertical plane oriented east-west and inclined about 55 degrees from the horizontal. The direction of tectonic transport is axis "a"-"a." It represents the direction of movement within the shear plane (cleavage) and, consequently, is the direction along which adjacent beds moved relative to each other. It was the slip movement along this direction that produced the drag folds observed in the Perseverance slates.

Faults

The rocks of the Juneau area are cut by thousands of small faults, many of which are too small to be mapped on mine maps, and all but four of which are too small to show on Plate 2. These four faults have been traced for many miles beyong the limits of the map of Juneau and Vicinity. All of them, with the exception of Silverbow fault are recognized from aerial photographs.

The total extent of large-scale faulting, such as represented by the faults shown, is not known in southeastern Alaska. Studies of aerial photographs indicate that all of the major faults of the northern part of southeastern Alaska are related to a major rift in the earth's crust that extends along Lynn Canal and Chatham Strait.

Because the sheared rocks in the fault zones are less resistant to erosion than the wall rocks, the faults ordinarily occupy linear depressions that are readily traced on aerial photographs. All of the major faults dip steeply (60° to 90°) and consequently their trace is approximately a straight line.

Most of the faults, both large and small, trend northwest and dip steeply northeast somewhat more steeply than the bedding and cleavage. A few faults strike east-west and are nearly vertical. A characteristic feature of all the faults in the Juneau area is the splits or branches from the main faults.

These generally split off at small angles and trend in such a manner as to become parallel to the bedding and foliation. In the Alaska-Juneau mire many of the splits leave the main Silverbow fault by curving to a position parallel to the bedding.

The faults range in thickness from a few inches to many feet. At places the faults are gouge-filled fractures with well-defined walls; at other places a fault zone is made up of hundreds of small shear surfaces with little or no gouge and poorly defined walls.

The material in Silverbow fault is commonly black with graphite. It is often brightly polished and striated. At some places the gouge is gray colored.

Only on Silverbow fault has the amount of relative movement been determined. Here the rock on the north side has moved west about 1400 feet and has been moved down an unknown amount butat least more than 1400 feet. It is believed that the movement on all of the faults was small for, except forSilverbow fault, mapping has not revealed any apparent displacement among the faults. It is believed that the faults represent zones of repeated shearing without much actual displacement.

SUMMARY OF ORIGIN OF STRUCTURAL FEATURES

Most of the subject matter in this section is more fully described at other places in this report. The material is merely summarized here to give the reader a less scattered outline of the structural events that have taken place in the Alaska-Juneau lode system.

The bedded rocks, from the Douglas Island volcanics to the Clark Peak schist, were originally laid down in a marine environment in a nearly horizontal position. The Douglas Island volcanics were deposited first and were successively and conformably overlain by the Treadwell, Gastineau, Perseverance, and Clark Peak rocks. At the close of the deposition of the Clark Peak schist widespread compression by mountain-building forces acting in a north-south direction tilted the rocks to their present northeasterly dipping and northwesterly striking attitude. The compression presumably acted during late Jurassic and early Cretaceous time. The Coast Range batholith was intruded at approximately the same time under the influence of the same orogeny.

The general structure of the area is monoclinal; the rocks generally strike northwest-southeast and dip about 70 degrees northeast. Well-developed cleavage is imposed on all the rocks, particularly the thin-bedded slates and tuffs; the cleavage coincides with the bedding except very locally where the thin-bedded rocks have been drag-folded by slippage parallel to bedding. There is no evidence of isoclinal folding.

In addition to the plane of the cleavage three other sets of joint planes are developed in the rocks. One of these, the cross joints, strike north-south and dip about 45 degrees to the west. One of the other two sets strikes N.34°W. and dip 40 degrees southwest, and the other strikes N.30°E. and dips 76 degrees to the northwest.

Stretching and corrugation have developed on the cleavage surfaces and coincide with the direction of the fold axes of the drag folds. In addition to lying within the cleavage the stretching lies in a hypothetical vertical plane that strikes N.84°W; measured in this vertical plane the lineation and drag-fold axes are inclined to the east 35 degrees.

Faults, that cut all the pre-Tertiary dikes and sills and post-date the mineralization, trend northwesterly and east-west, and dip steeply northeasterly and northerly respectively. Many subsidiary faults split and branch off from the main faults in a manner such that they become parallel to the bedding.

THE LODE SYSTEM

GENERAL FEATURES

The Alaska-Juneau lode system is confined exclusively to a band about 300 feet wide and 3-1/2 miles long in the footwall portion of the Perseverance slate. In addition to the slate the lode is composed of meta-gabbro sills, both rocks of which have been injected by a multitude of quartz veins carrying values in gold, silver, and lead. The greatest abundance of quartz veins, and the greatest values, are to be found in ground that it near the ends of meta-gabbro sills where they interfinger slate, both in meta-gabbro and slate.

Silverbow fault, one of the major faults in the Juneau area cuts across the lode system near its middle and divides it into two parts. The northern part contains the Ebner mine and the North Ore Body of the Alaska-Juneau mine. The southern part contains the South Ore Body of the Alaska-Juneau mine and the Perseverance mine.

Ore bodies in the Alaska-Juneau lode system are blocks of ground that contain abundant quartz veins near the ends of meta-gabbro sills. The shape of the ore bodies is very irregular and their boundaries are assay boundaries. In a general way the ore bodies dip to the northeast parallel to the regional dip of the slate and meta-gabbro sills, and rake within the plane of the dip in easterly direction parallel to the plunge of the meta-gabbro bodies and the direction of drag-fold axes and lineation within the slates.

The quartz veins are the gold-bearing portion of the lode system. For all practical purposes the slate and meta-gabbro wall rocks can be considered to be barren. The veins are from a few inches wide to 2 or 3 feet wide and may extend for several hundred feet along their strike and along their dip. Within meta-gabbro the veins are more definite in outline and attitude than they are within slate.

Quartz consitutes over 95 percent of the vein material. The other principal vein minerals are ankerite, pyrrhotite, arsenopyrite, galena, and sphalerite; these minerals are generally localized in the veins near or at the contact of the vein with the wall rock. Gold was the last mineral to crystallize and occupies fractures in the wall rock adjacent to the quartz veins.

The solutions that produced the quartz veins had a profound effect upon the adjoining meta-gabbro rock and a lesser effect upon the adjoining slate rock. The meta-gabbro sills, which are normally a green schistose hornblende gabbro, have been converted to a brown, non-schistose biotite rock with the addition of soda, potash, titanium, carbon dioxide, and phosphorous pentoxide, and the partial removal of iron, magnesia, lime, and combined water.

Large-scale, low-cost mining has been the only successful means of recovering gold from the Alaska-Juneau lode system. None of the veins is sufficiently persistent and large to be mined individually. The most successful method was to block cave large parts of the lode system followed by hand sorting to remove the barren slate and meta-gabbro.

VEINS

All of the gold bearing quartz veins in the Alaska-Juneau lode system are remarkably similar in their general aspects, although, as is to be expected, they are dissimilar in details. The majority of the veins range from a few inches to 2 or 3 feet wide and extend along their strike and dip several tens to a few hundred feet. They can be thought of as thin lenses of quartz interspersed throughout slate and meta-gabbro country rock.

Figure 8 illustrates the attitude of 87 gold-bearing quartz veins in the North Ore Body, and is representative of the attitude of the veins throughout the Alaska-Juneau lode system. A single vein maintains its attitude throughout with only negligible change. The atitude of the veins throughout the lode system is remarkably consistent. It should be noted, however, that the data on which figure 8 is based are somewhat selected as observations were taken only on those veins that had well-defined borders and were persistent in strike and dip. Probably 65 percent of the veins in the lode system meet these qualifications; 35 percent do not.

In general the veins strike N.36°W. and dip 78 degrees to the northeast. It is to be noted that the attitude of the veins is definitely cross-cutting with respect to the cleavage and bedding of the enclosing rocks. This fact becomes readily apparent by comparison of figures 5 and 8. This fact becomes even more apparent by observation of the underground workings, particularly the cross cuts of the Alaska-Juneau mine; the underground observer cannot fail to be impressed with the fact that the veins dip very steeply (75 to 80 degrees) to the northeast whereas the schistosity of the meta-gabbro and the cleavage of the slate dip less steeply (50 to 60 degrees). The fact that the cleavage and bedding strike about 15 degrees more to the northwest than does the vein is not readily apparent by observation underground.

The veins have very sharp and well-defined walls with both slate and meta-gabbro; although it appears that the walls in contact with the slates are somewhat better defined than are those in contact with meta-gabbro. Slate-vein contacts are knife-edge; meta-gabbro-vein contacts are comprised of about one-quarter to one-half inch of material transitional between meta-gabbro and vein material.

The veins are lacking in inclusions of wall-rock material. It is confidently estimated that less than one percent of the veins contain any wall-rock inclusions at all.

ORE BODIES AND ORE SHOOTS

Gold-bearing quartz veins are present within the Perseverance slate throughout a length of 3-1/2 miles from Mt. Juneau southeast to Sheep Mountain. Whether or not a given volume of rock within this distance is an ore body depends upon the number of quartz veins. All veins apparently contain approximately equal values in gold. A workable rule-of-thumb is, "the greater the number of veins, the higher the gold value" of a block of ground. The maximum intensity of veining, and consequent values, is in the North and South ore bodies of the Alaska-Juneau mine and the Perseverance mine; these blocks of ground are near the center of the mineralized ground extending from Mt. Juneau to Sheep Mountain.

The ore bodies are confined exclusively to a band about 300 feet wide in the footwall portion of the Perseverance slate, immediately adjacent to the underlying Gastineau volcanics.

There is no known reason that the ore bodies are confined to only the footwall portion of the Perseverance slate. All conditions, other than position, prevail in other portions of the Perseverance slate. Similarly there is no known reason that the ore bodies are confined to the particular position that they are along the strike of the Perseverance slate.

Individual ore shoots may be described as zones of abundant quartz veins. Ground not considered as ore contains lesser numbers of quartz veins. Boundaries of ore shoots are largely determined by assays. — why assays if you can see the veins — or assays?

Structurally ore shoots are to be found in zones containing many small meta-gabbro bodies or apophyses of a large meta-gabbro body within slate. Ore shoots have not been found within large meta-gabbro bodies or within slate zones not containing at least a few small meta-gabbro bodies.

Ore shoots are irregular-shaped zones, the long dimension of which is approximately parallel to the long dimension of the adjacent meta-gabbro body. This relationship is a consequence of the close correlation between ore shoots and interfingering meta-gabbro and slate.

FAULTS

The Alaska-Juneau lode system is cut by a multitude of faults. Most of them are parallel to the cleavage and bedding of the Perseverance slate, although some of them transect the bedding and cleavage at small angles either along the strike or dip. Branching and rejoining of the faults is very common. The greatest number of known faults are within the lode system near the footwall of the Perseverance slate; this apparent fact is probably a function of the many underground openings in the lode system as compared to other places in the Perseverance slate.

The major fault in the area is the Silverbow fault that transects the bedding and cleavage in an east-west direction (see plate 2). All other faults in the lode system are subsidiary branching faults that "horse tail" off from the Silverbow fault. Silverbow fault strikes east-west and dips 70 degrees north. It divides the Alaska-Juneau lode system into two parts, a north part including the North Ore Body and the Ebner mine, and a south part including the South Ore Body and the Perseverance mine.

Silverbow fault is a normal fault with a strike slip of about 1400 feet and a dip slip of at least 1400 feet. There is considerable doubt as to the amount of dip slip, for the lack of marker horizons in the vicinity of the fault preclude accurate determination of the amount of dip slip.

Silverbow fault is in reality a shear zone consisting of several subparallel gouge zones and intervening fractured rock. Branching off from Silverbow fault are thousands of faults, some of which rejoin the main fault, and others that depart from the trend of the main fault and within a few hundred feet away from Silverbow fault generally are parallel to the bedding.

The subsidiary faults branching off from Silverbow fault have broken the rock into a great number of blocks in such a complicated manner that it is impossible to determine the arrangement and position of the blocks prior to faulting. Thus, it is impossible to determine the amount and direction of movement along any faults other than Silverbow fault; and in the latter case, as mentioned above, the movement can be expressed only in the most general terms.

As near as can be determined, all faulting within the Alaska-Juneau lode system is part of a single system, the principal component being Silverbow fault; all other faults are subsidiary to it and are part of a system branching from it. In effect Silverbow fault represents a crustal break across the pre-existing bedding structure, with the subsidiary faults representing lesser resolved adjustments to the principal stress that resulted in

Silverbow fault.

The faulting is post-mineralization and pre-Tertiary dikes. Silverbow fault definitely cuts the lode system into two parts and, therefore, is post-mineralization. Many of the early engineers in the Alaska-Juneau mine assumed the gold ore was related to Silverbow fault and confined their explorations to areas adjacent to it. The fact that gold-bearing quartz veins are found at many places within and along fault zones led to the earlier belief that mineralization followed and was related to faulting. Subsequent observations and mining have demonstrated that the ore-bearing quartz in fault zones was dragged into that position.

The fact that Tertiary(?) basalt and diabase dikes cut across Silverbow fault without displacement prove that the faults are pre-Tertiary (?).

Inasmuch as the age of mineralization is post-Coast Range batholith (Upper Jurassic or Lower Cretaceous) and pre-Tertiary (?), it follows that the faulting occured some time during late Cretaceous.

MINERALOGY OF THE ORES

In spite of the long list of minerals that follows, the mineralogy of the ores of the Alaska-Juneau lode system is quite simple. The minerals include those of the veins, which are predominantly quartz with lesser amounts of ankerite, pyrrhotite, galena, sphalerite, ansenopyrite, and gold, and the minerals of the slates and meta-gabbros which comprise most of the host rock. The minerals of the slates are quartz and grap hite, and the minerals of the meta-gabbro are biotite, hornblende, ankerite, quartz, plagioclase, magnetite, and chlorite. In addition other minerals are found but they are distinctly lesser in amount than any of those listed above.

Metallic minerals

Gold (Au). Native gold occurs as flakes irregularly distributed in the quartz beins, in particular along the margins of the larger quartz veins where it is associated with galena, sphalerite, arsenopyrite, pyrrhotite, and ankerite. It occurs in minute fractures in ankerite and along sulfide contacts and more rarely in fractures in quartz. The presence of galena or sphalerite, or both, are said to be indicators of gold and it has been the xperience of the Alaska-Juneau mine that the best ore is that which contains sulfides, particularly galena or sphalerite, although quartz without sulfides does contain some gold.

Most, if not all, of the gold is free as is indicated by the mill recoveries of the Alaska-Juneau mill. In 1931 (Scott, 1932, pp. 375-382), for example, the average gold recovery was 79.58 percent of which 61.36 percent was recovered as bullion and 18.22 percent was recovered in the lead concentrate. These figures indicate that at least 80 percent of the gold is free, and assays made by the Alaska-Juneau mine of clean sulfide minerals indicate that probably 90 percent of the gold is free and not contained in the sulfides.

Smith (1941, pp. 167-168) reports that:

"Eight records of the gold from the placers in the Silver Bow Basin show fineness ranging from 772 to 827-3/4, the mathematical average of the eight records examined being 802-1/2. It is apparent that the gold is of distinctly local origin and has not been transported far or subjected long to atmospheric or other processes that might have effected much removal of the more soluble constituents of the 'dust.' In this connection it may be of significance to point out that the bullion received at the Seattle Assay Office in 1934 from the large gold mine that is situated near these placers contained 822 parts of gold and 148 parts of silver, with 30 parts unaccounted for in the assay. In 1935 the fineness of the lode gold from the same mine, tested in the same way, gave 820-1/2 gold and 148-1/2 silver. It is distinctly surprising that this bullion from the nearby lodes had a fineness so much higher than the average of that from the placers."

Scott (1932, p. 48) reports that the average fineness of the bullion of the Alaska-Juneau mine is 850 gold and 130 silver; this figure is even higher in gold than those reported by Smith. It should be noted that Scott's figures are based on ore from the North Ore Body and Ebner mine and consequently is more fine than gold from the south eastern part of the lode system.

Silver (Ag). Native silver is not known in the Alaska-Juneau lode system although silver-bearing minerals are in sufficient quantity to profitably recover silver. A considerable quantity of silver is combined with gold as is indicated above by an average fineness of 850 gold. The ratio of gold to silver recovered in the lead concentrates is about 1 to 1, indicating that part of the silver in the concentrates is very probably combined in some manner with galena and the rest of the silver with gold. Past production records of the Alaska-Juneau mine indicate that about 23 percnet of the silver is combined with gold and about 77 percent is probably combined with galena. Past production records indicate that the ratio of silver recovered to lead recovered i sabout one ounce of silver to 20 pounds of lead, and presumably this is about the ratio of silver to lead in the ore.

Pyrrhotite (FeS+S). The most abundant sulfide in the quartz veins is pyrrhotite. It is also found as impregnations of the biotized meta-gabbro adjacent to quartz veins. It occurs as irregular aggregates as large as 6 or 8 inches across in the quartz beinlets and as irregularly distributed small masses 1/8-inch across in biotized meta-gabbro. A conspicuous feature of the pyrrhotite is the iridescent tarnish that develops on all exposed surfaces and the ease with which it crumples when struck a sharp blow. It comprises slightly less than 1 percent of the rock trammed in the Alaska-Juneau mine. Specimens of pyrrhotite picked free of all visible impurities assayed from $0.41 to $2.89 (based on $20 gold) in gold per ton. Apparently very little gold is intimately associated with pyrrhotite.

In addition to being the most abundant sulfide mineral pyrrhotite is also much more widespread than any other sulfide mineral in the Alaska-Juneau lode system. It is the only sulfide mineral in many of the quartz veins, yet it always is present in veins containing other sulfide minerals as well.

A little pyrrhotite appears as exsolved veinlets in sphalerite, but most of it occurs as separate masses or intercrystallized with galena and sphalerite where these minerals are present.

Galena (PbS). Galena is erratically distributed in the veins of the Juneau area and generally is associated with sphalerite. It carries considerable silver and is recovered as a lead concentrate in the flotation system of the Alaska-Juneau mill. It does not crystallize in well-defined crystals, but occurs in quartz beins as irregular shaped, coarse-grained masses occupying spaces between earlier crystallized minerals. Galena is not found in the wall rocks. According to the mill records of the Alaska-Juneau mine the ore contains about 0.1 percent of galena, but inasmuch as all of the galena is in the veins it is apparent that the galena content of the beins is 3 or 4 times this figure. Galena picked free of all impurities assayed $0.83 to $1.45 per ton in gold (Based on $20 gold).

Sphalerite (ZnS). Sphalerite is intimately associated with galena and the two minerals have the same mode of occurence and are generally coarsely intercrystallized. Sphalerite is more abundant than galena; according to Alaska-Juneau mill records it comprises about 0.2 percent of the ore and makes up 3 or 4 times that percent of the vein material.

Sphalerite is nearly black, has a highly resinous luster, and rarely shows crystal forms, although it has a well-developed dodecahedral cleavage. Under the microscope it was observed that sphalerite contains numerous exsolved veinlets of pyrrhotite and this fact considered with its dark color suggests that the sphalerite is saturated with iron and is the variety marmatite.

Sphalerite from the Alaska-Juneau mine picked free of all impurities assayed $1.24 per ton in gold (based on $20 gold). Sphalerite was not recovered in the Alaska-Juneau mill for the values derived by recovering it would not justify the additional cost required.

Pyrite (FeS). Pyrite is not a particularly abundant metallic mineral in the ores of theAlaska-Juneau lode system. It is found as very small well-formed crystals in the quartz veins, as irregular masses impregnating biotized metagabbro, and as disseminated small crystals in the country rock. Pyrite comprises about 0.3 percent of the ore sent to the Alaska-Juneau mill. Pyrite picked free of all visible impurities assayed $1.65 per ton in gold (based on $20 gold).

Chalcopyrite ($CuFeS_2$). Compared to pyrrhotite, ansenopyrite, pyrite, sphalerite, and galena, chalcopyrite is extremely rare but apparently is quite widespread. It is present in such small amounts that no attempts have been made to recover it for its copper content. Some, of course, is recovered in the concentrates which are chiefly valuable for their gold, silver, and lead values. Small blebs of chalcopyrite in sphalerite can be seen with the microscope; these presumably resulted from unmixing of a solution of chalcopyrite and sphalerite.

<u>Arsenopyrite</u> (FeAsS). Arsenopyrite occurs in many of the quartz veins of the Alaska-Juneau lode system. It is lacking in the Ebner mine and most of the North Ore Body of the Alaska-Juneau mine, but towards the southeast it becomes increasingly more abundant and in the Perseverance mine it is second only to pyrrhotite in abundance, being at least twice as abundant as galena and sphalerite. It is associated with pyrrhotite in the quartz beins and shows a strong tendency to crystallize in clusters of well-defined crystals.

<u>Ilmenite</u> ($FeTiO_3$) and <u>magnetite</u> (Fe_3O_4). These two minerals are constituents of the igneous rocks and were not introduced by the ore-forming solutions. They occur as isolated euhedral crystals and as tiny irregular veins. They are distinguished by the fact that ilmenite is anisotropic whereas magnetite is isotropic. Some of the ilmenite is altered to leucoxene. Extremely fine-grained magnetite is present in much of the meta-gabbro where it apparently was formed by the breakdown of original ironbearing minerals.

how does he know this!
Is the size of a vein determining distance of origin?

Gangue minerals

Quartz (SiO_2). Quartz is by far the most abundant mineral introduced by the ore-forming processes. It comprises over 95 percent of the vein material. None of the quartz appears as introduced material in the wall rocks, although quartz is present in the wall rocks as an original constituent of the slates and quartzites. The vein boundaries are so sharp and distinct as to indicate that the wall rocks, regardless of whether they were slate, quartzite, or meta-gabbro, presented an impermeable barrier to siliceous fluids.

The vein quartz occupies fractures and is fine-grained, intercrystallized, and milky. Clear crystals with crystal faces are extremely rare and are found only in drusy cavities; the latter are very rare. Banding and crustiform structures in the quartz beins are entirely lacking and the whole appearance of all the quartz veins is quite massive.

Ankerite ($CaCO_3$*(Mg,Fe,Mn)CO_3). Ankerite is the second most abundant vein mineral and is an important constituent of biotized meta-gabbro wall rocks, where it may comprise as much as one third of the rock. Its characteristic occurrence in the quartz veins is on the extreme borders of the beins where it separates quartz from the wall rock. Not all veins carry ankerite nor does all the vein ankerite border the veins, but the presence of ankerite along the walls of the veins is an outstanding characteristic of the ores of theAlaska-Juneau lode system. Some ankerite occupies openings within the veins. It ranges in color from white to light gray to cream and it weathers to a deep rusty brown.

The index of refraction of the ordinary ray of the specimens examined is from 1.710 to 1.720, well above that for calcite (1.658) and dolomite (1.681), slightly above pure magnesite (1.700), and well below siderite (1.875).

Ankerite was not mentioned in the early reports on the lode system and it was mistakenly identified as calcite. The carbonates calcite, dolomite, and siderite are present, but they are most rare.

Ankerite is definitely one of the last minerals to crystallize for it occupies fractures that transect all of the other vein minerals except gold.

Calcite ($CaCO_3$). Calcite is rare as a vein mineral although it does occur in veins of the Perseverance mine. It is also present in some of the meta-gabbro rock. It is difficultly distinguished from ankerite by its whiter color, and is readily distinguished under the microscope by its index of refraction.

Dolomite ($CaMg(CO_3)$). Dolomite has been identified in the Alaska-Juneau ores by its curved faces and index of refraction. It has been noted in only a few places and in these cases it partially fills cavities in small fractures, along which leaching has occurred. The leaching is similar to that along Silver-bow and other faults and it is, therefore, concluded that dolomite is a distinctly later mineral than those introduced during gold mineralization.

Siderite ($FeCO_3$). Iron carbonate is very rare in the Alaska-Juneau ores and is found only in small seams and fractures whose nature suggests that siderite is a late mineral. It is distinguished by the index of refraction which is above 1.820 for the ordinary ray.

Tourmaline (Complex silicate of boron and aluminum, with also either magnesium, iron or the alkali metals present). Dark colored needles of tourmaline has been noted in a few of the quartz veins on the mainland and also as a minor accessory in the albite-mica schist near the Perseverance mine.

Rutile (TiO_2). Delicately striated, acicular needles of rutile are occasionally observed in clear quartz crystals that are rarely found in drusy cavities in the veins. Rutile may be present in the ordinary vein quartz and may have escaped detection because of the milky quality of the quartz.

Muscovite ($(H,K)AlSiO_4$). Muscovite occurs both as a rock mineral and as a vein mineral in the ores. All of the country rock, whether it be meta-gabbro, slate, or quartzite, contains varying amounts of sericite and muscovite, most of it probably having been derived from consitituents originally present in the rock. Muscovite is quite conspicuous filling extremely thin fractures in the veins. It more or less coats the walls of the fractures with a thin film of silvery muscovite. The quantity of muscovite is very small, but its conspicuourness is disproportionate to the amount present for it coats so many fracture surfaces, particularly in the veins. It is concluded that vein muscovite is a late hydrothermal mineral judging from the fact that it coats fracture surfaces in vein quartz.

Biotite ($H_2K(Mg,Fe)_3Al(SiO_4)_3$). Biotite is the most conspicuous and characteristic mineral of the metasomatic changes connected with the wall-rock alteration of the meta-gabbro. It is never present as a vein mineral. It is a dark brown color and is pleochroic. Biotite in brown meta-gabbro imparts the brown color to the altered rock and characteristically is randomly oriented, in marked contract to the minerals of green meta-gabbro which show a distinct linear and plan structure.

Chlorite (Hydrous silicates of aluminum with ferrous iron and magnesium). Chlorite is not a vein mineral; it is found in the slate and meta-gabbro country rocks where it is derived from the alteration of ferromagnesian minerals. It is found in both meta-gabbro and slate but seldom in large amounts.

Hornblende (Hydrous silicate of aluminum, sodium, calcium, and iron and/or magnesium). Hornblende is not known to occur in the Alaska-Juneau lodes system as a vein mineral. It is, however, the most conspicuous and abundant mineral of the green meta-gabbro and also is in the brown meta-gabbro. It occurs as long prismatic crystals arranged in planar orientation parallel to the schistosity of the slates. A preferred linear orientation was not observed. In the meta-gabbro, it has been postulated that hornblende is an alteration product of pyroxene. Adjacent to the veins, where wall-rock alteration is intense, hornblende has altered to biotite and other minerals.

Hornblende in meta-gabbro is a pale green to dark green color. The optic angle is large (nearly 90 degrees), the angle Z to c is about 23 degress, the optic sign is negative. Alpha is about 1.645, beta about 1.660 and gamma about 1.670. It is pleochroic in shades of yellowish green to dark bluish green. The above optical data indicate that this amphibole, rather loosely called hornblende, is a member of the pargasite-hornblende series.

Epidote ($HCa_2(Al,Fe)_3Si_3)_{13}$) and zoisite ($HCa_2Al_3Si_3O_{13}$). Of these two minerals zoisite is by far the most common; epidote being found only in slates containing some admixed tuffaceous material. Zoisite is common in the meta-gabbro where it occurs as a metamorphic mineral formed during the metamorphism of gabbro to meta-gabbro. Zoisite cannot be distinguished in the hand specimen, but when seen with the microscope it occurs as fine-grained disseminated crystals within the meta-gabbro.

Plagioclase (70 percent of $NaAlSi_3O_8$ and 20 percent of $CaAl_2Si_2O_8$). Felspar is a prominent constituent in some of the meta-gabbro bodies. It is not a constituent of the beins in the lode system. Feldspar in the meta-gabbro is generally considerably altered, granulated and sericitized.

The most common feldspar has been identified as oligoclase-andesine on the basis that its index of refraction for alpha is 1.545 and for gamma is 1.555.

Graphite (C). The Perseverance slate contains an abundance of carbonaceous matter, most of which has been converted to graphite by regional dynamic metamorphism and by the heated gold-bearing solutions. It is not found in the veins themselves except in those rare places where the introduction of vein material has mechanically torn pieces of black slate containing graphite from the wall rocks and included them within the veins. Graphite is particularly abundant along some of the larger faults such as Silverbow fault, where in some parts the gouge may contain as much as 25 to 30 percent of graphite. The presence of so much graphite in some of the larger faults is unexplained.

The presence of graphite in the ores has been the cause of considerable trouble in the Alaska-Juneau mill, for it is a slippery mineral that forms a greasy slime that interferes with tabling and amalgamation.

Garnet ($Fe_3Al_2Si_3O_{12}$). Garnet is not a common mineral in the Alaska-Juneau lode system. Its most common mode of occurrence is as subhedral small crystals immediately adjacent to the quartz veins, suggesting that the veins may have provided the requisite heat and perhaps some of the chemical constituents necessary for the formation of garnet. Garnet is abundant in the Clark Peak schist where it was produced as a consequence of the etamorphism attendant with the Coast Range intrusion. However, metamorphism in the Perseverance slate was not of sufficient intensity to produce garnet except adjacent to the quartz veins.

The garnet is very dark brown to almost black, due in large part to the abundant graphite inclusions in the garnet. Quartz inclusions also are abundant. They apparently formed after the regional schistosity was produced in the slates, for the inclusions are oriented parallel with the cleavage of the rocks. This observation confirms that the presence of the garnets is due to the quartz veins for the quartz veins likewise post-date regional schistosity.

Apatite ($(CaF)Ca_4(PO_4)_3$). Apatite is a prominent minor constituent of brown meta-gabbro, much of it having been formed during the processes of wall-rock alteration when relatively large amounts of phosphorous pentoxide were introduced by the vein-forming solutions. A little apatite was present in the original gabbroic rocks. Apatite occurs as extremely small euhedral crystals. It is not a vein mineral.

Sphene ($CaTiSiO_5$). Sphene is a prominent minor constituent of meta-gabbro. During the metasomatic changes accompanying wall-rock alteration some titanium oxide was introduced and as a consequence brown meta-gabbro contains slightly more titanite than does green meta-gabbro. It occurs as small euhedral crystals sparsely distributed in meta-gabbro. Some sphene appears to have altered to leucoxene. Sphene is not a vein mineral.

MINERAL ZONING

A zonal change of the sulfide minerals is quite distinct from northwest to southeast along the Alaska-Juneau lode system. Near the northwest and in the Ebner mine, sulfide minerals are not common by comparison with veins to the southeast, and pyrrhotite is by far the most conspicuous sulfide mineral. Toward the southeast end of the lode system galena and sphalerite gradually appear and become increasingly abundant although they never attain the abundance of pyrrhotite. Arsenopyrite appears as a conspicuous mineral only in the Perseverance mine at the southeast end of the lode system. The abundance of pyrrhotite is unchanged throughout the lode system.

The gold-silver ratio in the Ebner mine near the northwest end of the lode system is 7 to 1 by weight, and the gold-silver ratio in the Perseverance mine near the southeast end of the lode system is 1 to 1.

In the North Ore Body of the Alaska-Juneau mine pyrrhotite is the dominant sulfide mineral with lesser amounts of sphalerite and galena. No data are available on the gold-silver ratio.

In the South Ore Body pyrrhotite is the dominant sulfide mineral although galena and sphalerite are somewhat more abundant than in the North Ore Body.

Arsenopyrite is present in increasing amounts toward the adjoining Perseverance ground. The gold-silver ratio is 1-1/2 to 1 by weight.

In the Perseverance mine arsenopyrite is somewhat more abundant than either galena or sphalerite, but pyrrhotite is most abundant. As stated above the gold-silver ratio is 1 to 1 by weight.

There is no detectable change in vein mineralogy or gold-silver ratio at depth at any place in the Alaska-Juneau lode system. This is so in spite of the fact that within the North Ore Body mining has exposed the lode system throughout a vertical distance of over 2,000 feet.

WALL-ROCK ALTERATION

General features.

The meta-gabbro sills of the Alaska-Juneau lode system have been profoundly altered by regional dynamic metamorphism and the vein-forming solutions. Regional dynamic metamorphism has converted "normal" gabbro into a green amphibole-rich rock referred to as green meta-gabbro. The vein-forming solutions have changed green meta-gabbro into a biotite-rich rock referred to as brown meta-gabbro. These changes are considered below from the standpoint of chemical changes and mineralogical changes. Table 4 illustrates the type and extent of the chemical changes.

Table 4, table of chemical analyses showing changes in composition in alteration from normal gabbro to green meta-gabbro to brown meta-gabbro

Constituents	Normal gabbro	Green meta-gabbro					Brown meta-gabbro				Percent gain or loss, in change from green to brown
sample	no. 61	208	64	11A	1	Average	60	29	2	Average	
	percent			percent					percent		
SiO_2 - - - -	47.5	47.76	49.7	49.8	48.30	48.89	44.69	41.3	52.92	46.30	-5.3
Al_2O_3 - - -	16.0	13.98	20.2	15.1	13.59	15.72	14.97	17.9	20.53	17.80	----
Fe_2O_3+FeO - -	8.2	10.71	7.8	7.9	13.56	9.99	7.65	6.2	8.38	7.41	-25.8
MgO - - - - -	7.4	9.07	4.7	7.9	6.29	6.99	3.92	5.8	2.43	4.05	-42.1
CaO - - - - -	10.5	12.71	9.8	10.2	11.09	10.95	10.07	10.9	4.76	8.58	-21.6
Na_2O - - - -	----	1.65	----	----	2.16	1.90	2.36	----	4.67	3.51	+84.8
K_2O - - - - -	----	0.20	----	----	1.55	0.87	1.76	----	2.96	2.36	+171.5
H_2O- - - -	----	0.22	----	----	0.00	0.11	0.36	----	0.18	0.27	+145.5
H_2O+ - - -	----	2.06	----	----	2.06	2.06	0.20	----	1.58	0.89	-56.8
TiO_2 - - - -	----	1.48	----	----	1.01	1.24	2.25	----	0.99	1.62	+32.2
ZrO_2 - - - -	----	none	----	----	----	none	0.02	----	----	none	•
CO_2 - - - -	----	none	----	----	none	none	8.47	----	----	8.47	•
P_2O_5 - - - -	----	0.12	----	----	0.26	0.19	0.26	----	0.57	0.41	+116.0
SO_3 - - -	----	none	----	----	----	none	none	----	----	none	----
Cl - - - - -	----	----	----	----	----	----	none	----	----	none	----
F - - - - - -	----	none	----	----	----	none	none	----	----	none	----
S - - - - -	----	0.04	----	----	none	0.02	----	----	----	----	----
MnO - - - -	----	0.14	----	----	0.25	0.19	0.14	----	0.28	0.21	----
BaO - - - -	----	tr.	----	----	----	tr.	0.14	----	----	0.14	•
SrO - - - -	----	none	----	----	----	none	----	----	----	----	----
FeS_2 - - - -	----	----	----	----	----	----	0.27	----	----	0.27	----
Fe_7S_8 - - -	----	----	----	----	----	----	2.25	----	----	2.25	----
Less O_2 - -	----	0.02	----	----	----	----	----	----	----	----	----
	89.6	100.12	92.2	90.9	100.12	99.14	99.78	92.1	100.25	104.06	

Table 4 (Cont.)

Sample No. 61. Data from Wernecke (1918). Gabbro from center of tunnel No. 1, Alaska-Juneau railroad. George Swarva, Analyst. The rock is a coarse-grained, grayish-green hornblende gabbro. The hornblende was formed from augite which forms the centers of some of the hornblende crystals. Labradorite is the other prominent constituent and it is partially altered to quartz, albite, and zoisite. Minor amounts of titanite and magnetite are present.

Sample No. 208. Data from Spencer (1906). Green meta-gabbro from easternmost ill on the north side of Gold Creek. George Steiger, analyst. Green hornblende in felted aggregates composes about 75 percent of the rock. The rest of the rock is finely granulated feldspar with some quartz.

Sample No. 64. Data from Wernecke (1918). Green meta-gabbro from near the blacksmith shop in Gold Creek tunnel. George Swarva, analyst. This specimen from the same body as sample No. 61 and represents a beginning stage in the metamorphism of a gabbro. It is an amphibolite composed of acicular uralitic hornblende and finely granular quartz and zoisite apparently derived from feldspar. Minor amounts of apatite and magnetite are present.

Table 4 (Cont.)

Sample No. 11A. Data from Wernecke (1918). Green meta-gabbro from near face of 415 south crosscut, Alaska-Juneau mine. George Swarva, analyst. The rock is a dense fine-grained dark green amphibolite. It is a completely recrystallized gabbro.

Sample No. 1. Data from Knopf (1912, pp. 37-39). Green meta-gabbro from northwest side of Mendenhall Glacier, Eagle River region. J. G. Fairchild, analyst. The rock is dark olive-green and fine-grained with black euhedral crystals of actinolitic hornblende as phenocrysts. Amphibole is the dominant constituent; zoisite and epidote are abundant, granular albite is interstitial and biotite is present in small amounts. Titaniferous magnetite and apatite are accessories.

Sample No. 60. Data from Spencer (1906, p. 63). Brown meta-gabbro from the Ebner ore body. George Steiger, analyst. Rock is estimated to consist of 45 percent of quartz, 22 percent of mica, 20 percent of carbonates, 10.5 percent of titaniferous magnetite, and 2.5 percent of sulfide minerals.

Sample No. 29. Data from Wernecke (1918). Brown meta-gabbro from tongue of meta-gabbro below 410 stope, Alaska-Juneau mine. George Swarva, analyst. It is a dense, fine-grained, dark brown, sugary rock.

Table 4 (Cont.)

Sample No. 2. Data from Knopf (1912, pp. 37-39). Brown meta-gabbro from northwest side of Mendenhall Glacier, Eagle River region. J. G. Fairchild, analyst. It is a fine-grained, black rock composed largely of biotite of an intensely pleochroic variety in fine flakes and tufted or fan-shaped forms. Albite and zoisite are the other prominent minerals, and chlorite, calcite, apatite, and pyrrhotite are minor constituents.

Chemical changes

It is unfortunate that only a partial analysis is available of the so-called "normal" gabbro from the Alaska-Juneau lode system. However, it is apparent from the chemical analyses that the change from a gabbro to green meta-gabbro involves essentially no change in chemical composition. Northing has been added or removed, (Compare normal gabbro with average analysis for green meta-gabbro). The change is purely a change in the mineralogy and physical character of the rock and was accomplished by heat, pressure, and the water vapors enclosed in the original rock.

At only one place in the lode system is there a gabbro that is only partially metamorphosed to green meta-gabbro. All of the other gabbro bodies are so completely metamorphosed that all traces of the original gabbro are destroyed. Sample number 61 in table 4 is a specimen from a gabbro intrusive, only part of which was converted to green meta-gabbro.

That the green meta-gabbro was actually derived from a gabbro-type of rock is indicated by a comparison of the chemical analyses of the green meta-gabbro in the lode system with the mean of 41 analyses of gabbros, as shown in the table below.

	1	2	3 Basalt (Daly)
SiO_2 ----------	48.2	48.9	49.1
Al_2O_3 --------	17.9	15.7	15.7
Fe_2O_3 + FeO --	9.2	10.0	11.7
MgO ----------	7.5	7.0	6.2
CaO ----------	11.0	10.9	9.0
Na_2O --------	2.5	1.9	3.1
K_2O ----------	0.9	0.9	1.5
H_2O ----------	1.4	2.1	1.6
TiO_2 ---------	1.0	1.2	1.4
MnO ----------	0.1	0.2	.3
P_2O_5 --------	0.3	0.2	.4
	100.0	99.0	

Note low Na_2O – no Na added in "pre-hydrothermal" meta.

1. Mean of 41 analyses of gabbro (including olivine gabbro). From Daly, R. A., Igneous rocks and their origin, p. 27, 1914.

2. Mean of 4 analyses of green meta-gabbro from the Alaska-Juneau lode system. Data from table 4.

The similarity of the two sets of analyses is remarkable and there can be no doubt that the parent rock of the green meta-gabbro is a gabbro.

Unlike the change from normal gabbro to green meta-gabbro, which was largely a physical change, the change from green meta-gabbro to brown meta-gabbro is largely a chemical change. Changes in mineralogy, of course, occurred in both conversions. Reference to table 4 reveals that the change from green meta-gabbro to brown meta-gabbro, if the amount of Al_2O_3 is assumed to have remained unchanged, involved the addition of relatively large amounts of soda, potash, titanium, carbon dioxide, and phosphorous, and the removal of considerable amounts of iron, magnesia, lime, and combined water. The figures also suggest that silica was removed, although the difference between the sets of analyses is too small to be convincing.

Mineralogical changes

The original gabbro consisted of hornblende, augite, and labradorite in various degrees of alteration, with minor amounts of titanite and magnetite. The hornblende was derived from augite and in the green meta-gabbro augite still comprises parts of the centers of some of the hornblende crystals.

Metamorphism to produce the green meta-gabbro is a consequence of regional dynamic metamorphism. It involved the alteration of augite to hornblende and the breakdown of the feldspar to othoclase, zoisite, and albite. The resulting rock is somewhat variable in mineralogy, but the writer estimates, on the basis of numerous thin-section observations, that an approximate mineralogical analysis of green meta-gabbro is as shown in the following listing. Similarly an approximate mineralogical analysis is given for brown meta-gabbro.

	Green meta-gabbro percent	Brown meta-gabbro percent
Hornblende	49.5	---
Albite	16.0	30.0
Orthoclase	5.0	---
Zoisite	25.0	15.0
Quartz	---	5.0
Biotite	---	26.0
Ankerite	---	18.0
Apatite	0.5	1.0
Titanite	3.0	4.0
Magnetite	1.0	1.0
	100.0	100.0

The change from green meta-gabbro to brown meta-gabbro is locally known as biotization, because the new biotite is such a conspicuous constituent. As noted earlier, the process of biotization in the Alaska-Juneau lode system was caused by the addition of soda, potash, titanium, carbon dioxide, and phosphorous pentoxide, and the removal of part of the iron, magnesia, lime and combined water. Because of these chemical changes the minerals previously present were not stable, and in the presence of heat and water, new minerals were formed. Hornblende was not stable in the new environment and it is lacking in all biotized meta-gabbro. The introduction of soda resulted in the formation of albite. Potash was made available from the vein-forming solutions and the breakdown of orthoclase provided an additional amount to be used by biotite. Some of the magnesia, iron, and lime combined with introduced carbon dioxide to form ankerite. The additional amounts of titania and phosphorous pentoxide resulted in an increased quantity of titanite and apatite, respectively, in brown meta-gabbro.

Examples of biotization as wall-rock alteration are rare, but its occurrence in a few localities has been noted in the literature - at Rossland, British Columbia; Sullivan, British Columbia; Copper Mountain, British Columbia; and in the Kolar gold district of India.

At Rossland, Drysdale (1915) reports that the country rock is an augite porphyrite composed of phenocrysts of augite, hornblende, and plagioclase in a groundmass of plagioclase and hornblende. Adjacent to the veins the feldspars of the augite porphyrite are clouded and silicified, and in places the augite is altered to uralite and biotite. The altered augite porphyrite is richer in magnesium, potassium, and iron, and lower in silica, calcium, and sodium that the fresh augite porphyrite.

In the Kolar gold field of India the country rock is hornblende schist. In the vicinity of the quartz lodes a "characteristic brown mica is abundantly developed, and so much so is this the case that its plentiful occurrence may be regarded as an indication of the near presence of a lode" (Hatch, 1901, p. 7). It is of interest to note the similarity of wall-rock alteration at

Kolar and at the Alaska-Juneau lode system where the occurrence of biotite in meta-gabbro also is an indication of the near presence of quartz veins.

At Copper Mountain (Dolmage, 1934, pp. 27 and 55) the feldspar-augite country rock, where invaded by the Copper Mountain stock, is intensely biotized and in places almost completely converted to biotite.

At the Sullivan mine, British Columbia (Swanson, 1945, pp. 645-667), the dominant type of alteration is tourmalinization, albitization, and chloritization, but at places the wall rocks are rich in biotite. The biotite occurs as spots in the sediments.

On the basis of his studies in the Marysville mining district Barrell concludes that the transformation of hornblende into biotite is a "mark of hydrothermal metasomatism, through perhaps a temperature but a little lower than under the more intense conditions closer to the contact" (Barrel, 1907, p. 140).

Ankeritization and albitization, in addition to biotization, are conspicuous alteration processes in the wall rocks of the Alaska-Juneau lode system. It is of interest to note that ankeritization is a dominant process of wall-rock alteration in the Mother Lode system of C lifornia, which is remarkably similar in many other respects to the gold deposits of the Alaska-Juneau lode system.

Knopf (1929) reports that the chief characteristics of the wall-rock alteration in the Mother Lode is the addition of carbon dioxide, potassium, and sulfur, and the removal of silica.

MINING AND MILLING

It is not the purpose of this report to exhaustively describe the mining and milling methods that were employed by the mines in the Alaska-Juneau lode system. However, because there were several outstanding mining and milling techniques developed by the mines in their efforts to treat these ores, it is deemed worthwhile to mention some of the methods used.

Although individual veins of the Alaska-Juneau lode system are high grade none of them is sufficiently large and continuous to be selectively mined. Early attempts were made to mine individual veins but failures soon made it apparent that the only profitable method was to mine on a large scale, taking both vein material and intervening barren material.

Large-scale mining and milling techniques were developed and were very successful at the Alaska-Juneau mine, although similar techniques applied to the Alaska-Gastineau mine ended in failure. Large stopes, some of which are caved to the surface to make glory holes, are cut and caved in those zones of rock that were previously tested for profitable gold values. The caved and broken rock was drawn off at the bottom of the stopes through grizzlies and loaded into cars and trammed to the mill.

After primary crushing the rock was moved on an endless belt where it was hand-picked - the barren slate and meta-gabbro being rejected and all material containing quartz was retained and further milled. As the result of hand-picking the average tenor of ore milled was increased to 0.086 ounces of gold per ton, whereas the average tenor of all rock mined, (including vein and intervening material), is 0.045 ounces of gold per ton. Approximately 45 percent of the material mined is rejected by hand-sorting. This method is successful only because unskilled (and consequently inexpensive) labor can readily distinguish between the gold-bearing vein material which is white and the barren material which is dark colored. Without hand-sorting the additional cost of milling nearly twice as much material would never have permitted a profit.

The Alaska-Juneau mine was one of the larger gold mines of the world, and for many years mined over 12,000 tons of rock per day. It is the only mine in the world to have successfully operated on ore of such low grade. In recent years the average recovery has been $1.15 per ton, mined at a total cost of 72 cents per ton.

The reader is referred to reports by Scott (1932) and Metzgar (1932) for comprehensive descriptions of the mining and milling methods employed by the Alaska-Juneau mine.

BIBLIOGRAPHY

Ball, S. H., 1916, Geological report upon the property of the Alaska-Gastineau Mining Company near Juneau, Alaska: unpublished private report.

Barrell, Joseph, 1907, Geology of the Marysville mining district, Montana: U. S. Geol. Survey Prof. Paper 57, 178 pp.

Bradley, P. R., 1932, History, organization, and outlook (of the Alaska-Juneau enterprise): Eng. and Min. Jour., vol. 133, no. 9, pp. 460-465.

Buddington, A. F., 1923, Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739-b, pp. 51-75.

Buddington, A. F., 1929, Geology of Hyder and vicinity, southeastern Alaska: U. S. Geol. Survey Bull. 807, 124 pp.

Buddington, A. F, and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800, 398 pp.

Cairnes, C. E., 1924, Coquihalla area, B.C.: Can. Geol. Survey Mem. 139, 187 pp.

Chapin, Theodore, 1919, The structure and stratigraphy of Gravina and Revillagigedo islands, Alaska: U. S. Geol. Survey Prof. Paper 120-d, pp. 83-100.

Cockfield, W. E., and Bell, A. H., 1926, Whitehorse district, Yukon: Can. Geol. Survey Mem. 150, 62pp.

Dolmage, Victor, 1926, Tatla-Bella Coola area, Coast district, B.C.: Can. Geol. Survey Summ. Rept. for 1925, pt. A, pp. 155-163.

Dolmage, Victor, 1934, Geology and ore deposits of Copper Mountain, British Columbia: Can. Geol. Survey Mem. 171, 69 pp.

Drysdale, C. W., 1915, Geology and ore deposits of Rossland, British Columbia: Can. Geol. Survey Mem. 77, 317 pp.

Eakin, H. M., 1922, Geology and ore deposits of Juneau, Alaska: U. S. Geol. Survey unpublished report.

Federal Power Commission and U. S. Forest Service, 1947, Water powers (of) southeast Alaska.

Graton, L. C., 1916, Results of microscopical examination of rock and ore from the Juneau region, Alaska: unpublished private report.

Hanson, George, 1924, Reconnaissance between Skeena River and Stewart, B.C.: Can. Geol. Survey Summ. Rept. for 1923, pt. A., pp. 29-45.

Hatch, F. H., 1901, The Kolar gold-field: Geol. Survey of India Mem. vol. 33, part 1.

Knopf, Adolph, 1911, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 58 pp.

Knopf, Adolph, 1912, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 61 pp.

Knopf, Adolph, 1929, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, 88 pp.

Metzgar, L. H., 1932, Development, mining, and transportation (of the Alaska-Juneau enterprise): Eng. and Min. Jour., vol. 133, no. 9, pp. 489-492.

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

Overbeck, R. M., 1919, Geology and mineral resources of west coast of Chichagof Island, (Alaska): U. S. Geol. Survey Bull. 692-b, pp. 91-136.

Rickard, T. A., 1932, A history of American mining: McGraw-Hill Book Co.

Rogers, A. H., 1916, Report on the ore reserves of the Alaska-Gastineau mine, Alaska: unpublished private report.

Scott, W. P., 1932, Milling methods and ore-treatment equipment (of the Alaska-Juneau enterprise): Eng. and Min. Jour. vol. 133, no. 9, pp 475-482.

Smith, P. S., 1941, Fineness of gold from Alaska placers: U. S. Geol. Survey Bull. 910-c, pp. 147-272.

Smith, P. S., 1942, Past lode-gold production from Alaska: U. S. Geol. Survey Bull. 917-c, pp. 159-212.

Spencer, A. C., 1906, The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, 137 pp.

Swanson, C. O., and Gunning, H. C., 1945, Geology of the Sullivan mine: Can. Inst. Min. and Met. Trans., vol. 48, pp. 645-667.

Twenhofel, W. S., 1952, Shore-line changes along the Pacific coast of Alaska: to be published in the Am. Jour. Sci.

U. S. Weather Bureau, Dept. of Commerce, 1949, Climatological data: vol. 35, no. 13.

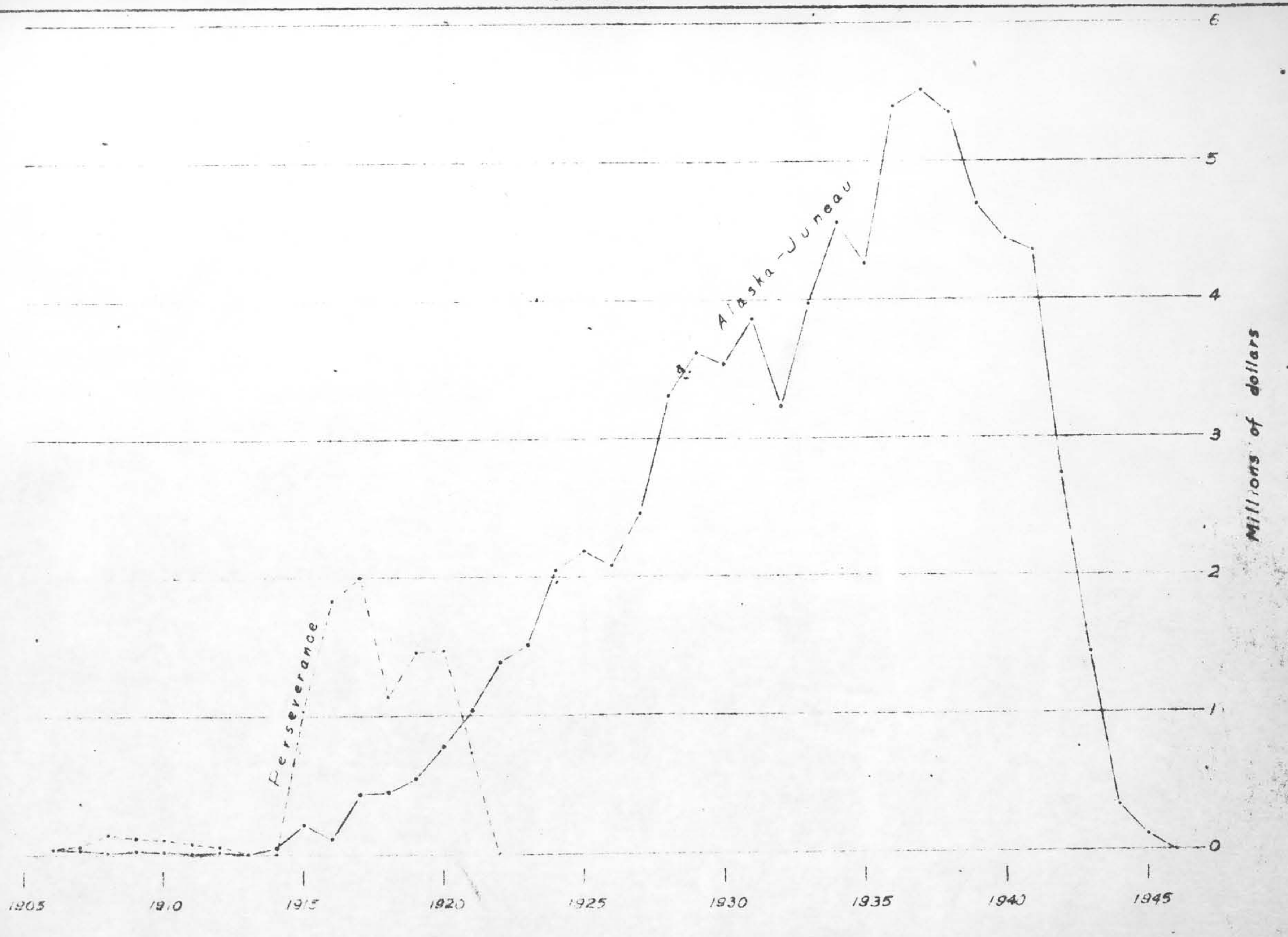
Wernecke, Livingston, 1918, Geology of the Alaska-Juneau lode system: unpublished private report.

Wernecke, Livingston, 1932, Geology of the ore zones (of the Alaska-Juneau enterprise): Eng. and Min. Jour., vol. 133, no. 9, pp. 493-499.

Wright, C. W., 1906, A reconnaissance of Admiralty Island, (Alaska): U. S. Geol. Survey Bull. 287, pp. 138-154.

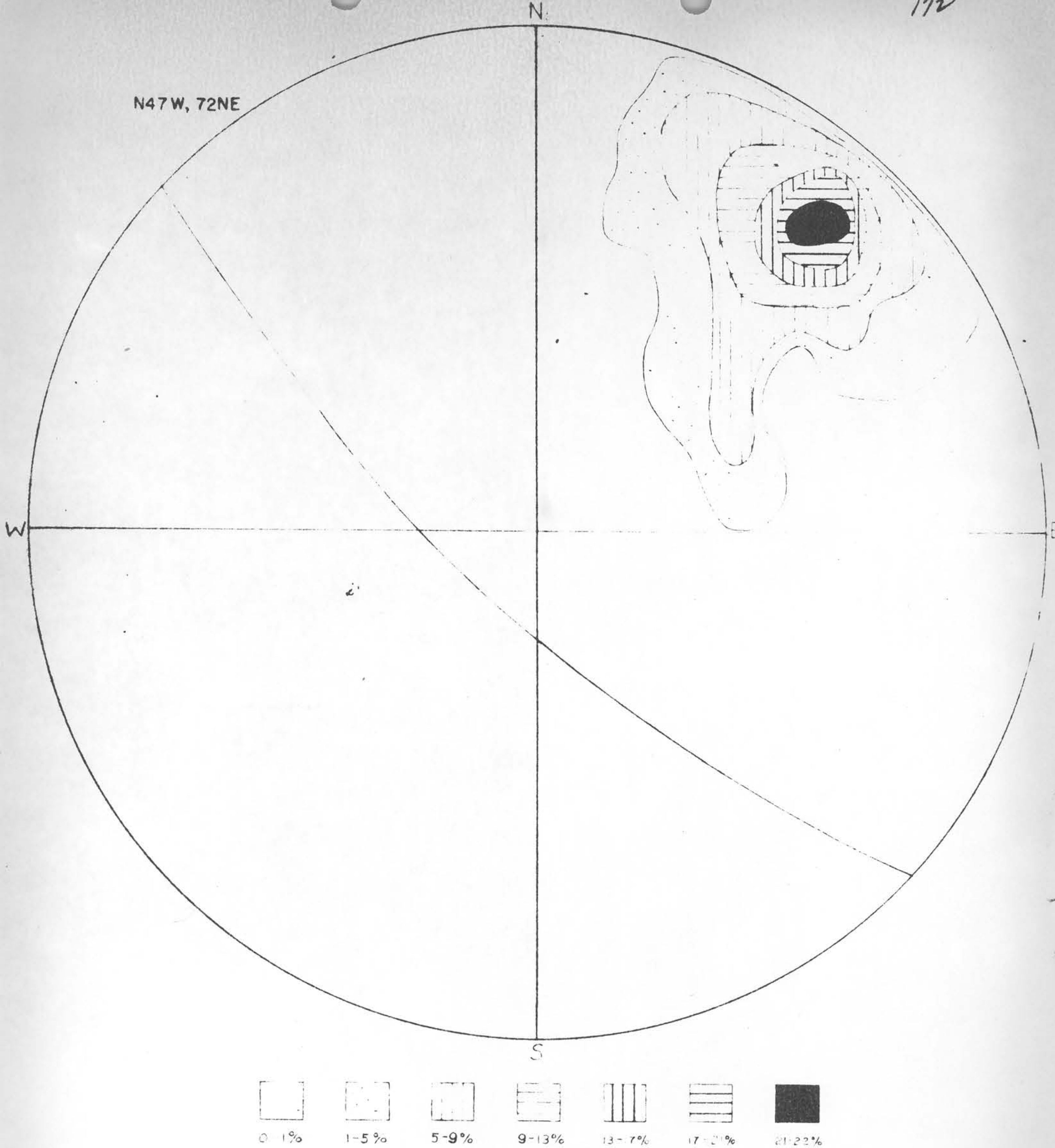
Wright, C. W., and Wright, F. E., 1908, The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 210 pp.

FIGURE 3



YEARLY PRODUCTION, ALASKA-JUNEAU LODE SYSTEM

FIGURE 4

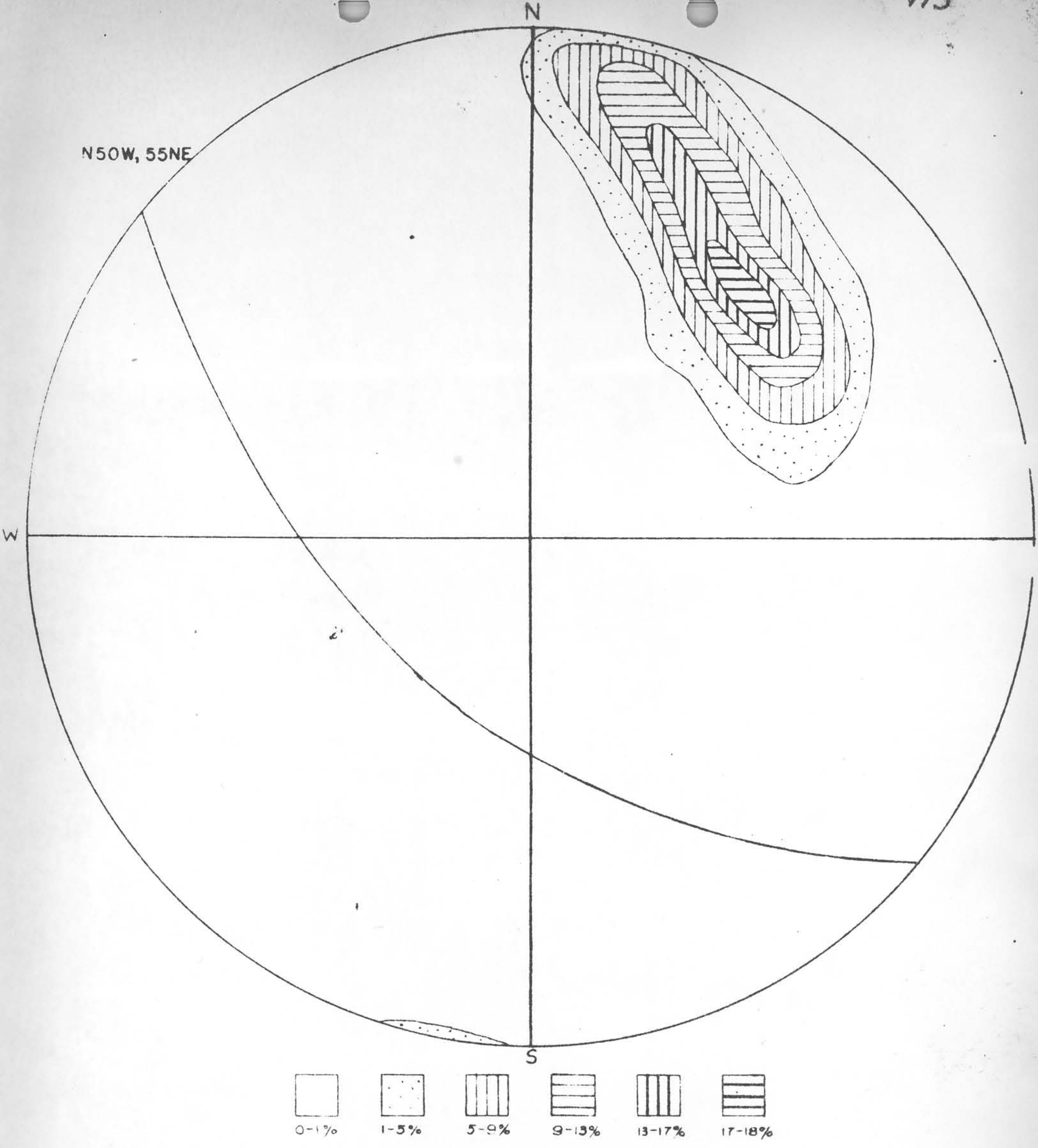


ATTITUDE OF BEDDING AND CLEAVAGE

Juneau area, Alaska

218 observations with poles plotted on upper hemisphere of spherical equal-area net

FIGURE 5

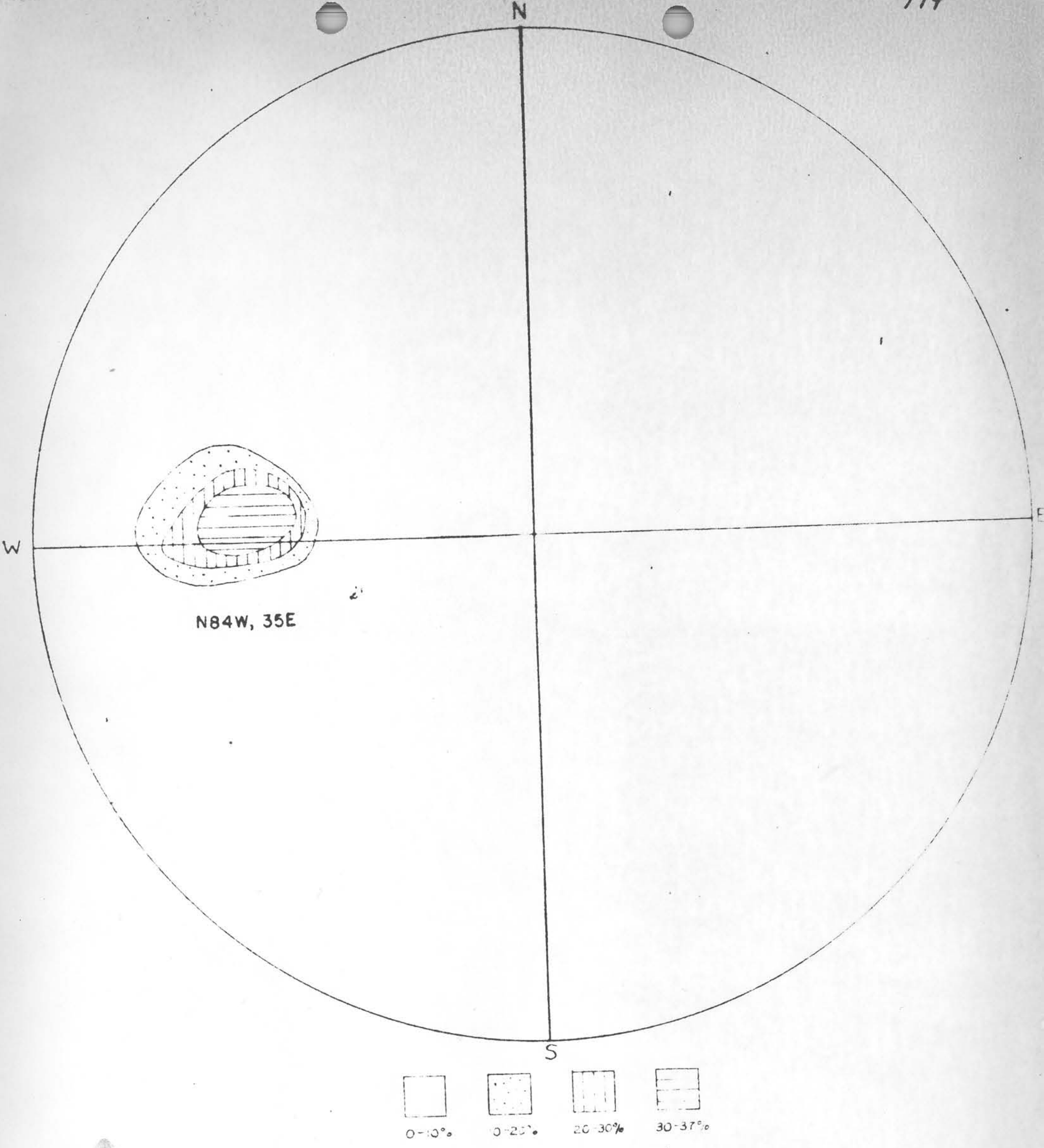


ATTITUDE OF BEDDING AND CLEAVAGE

Alaska - Juneau mine, Alaska

382 observations with poles plotted on upper hemisphere of spherical equal-area net

FIGURE 6

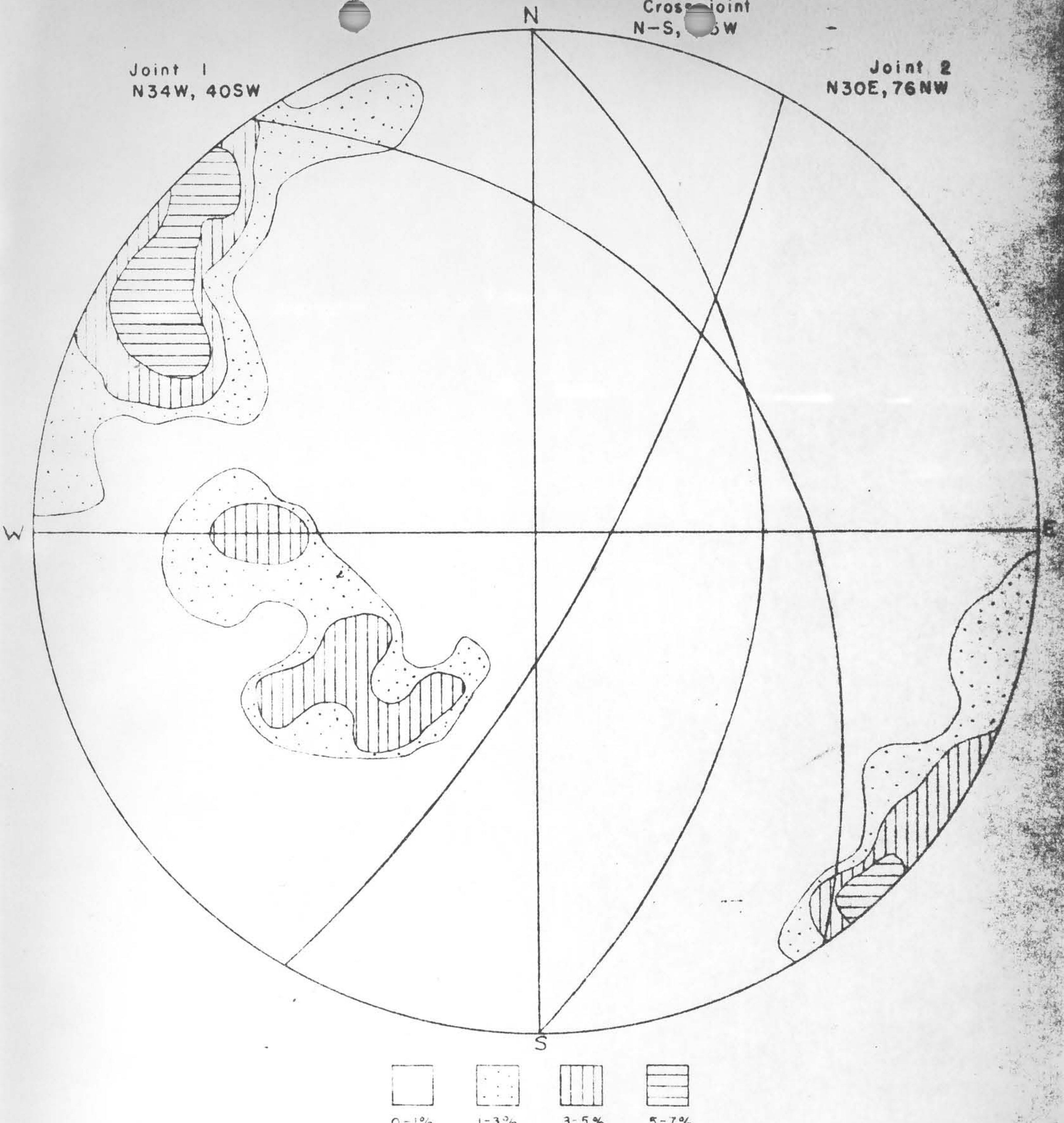


ATTITUDE OF LINEATION AND AXES OF DRAG FOLDS,

Alaska — Juneau mine, Alaska

46 observations plotted on upper hemisphere of spherical equal-area net

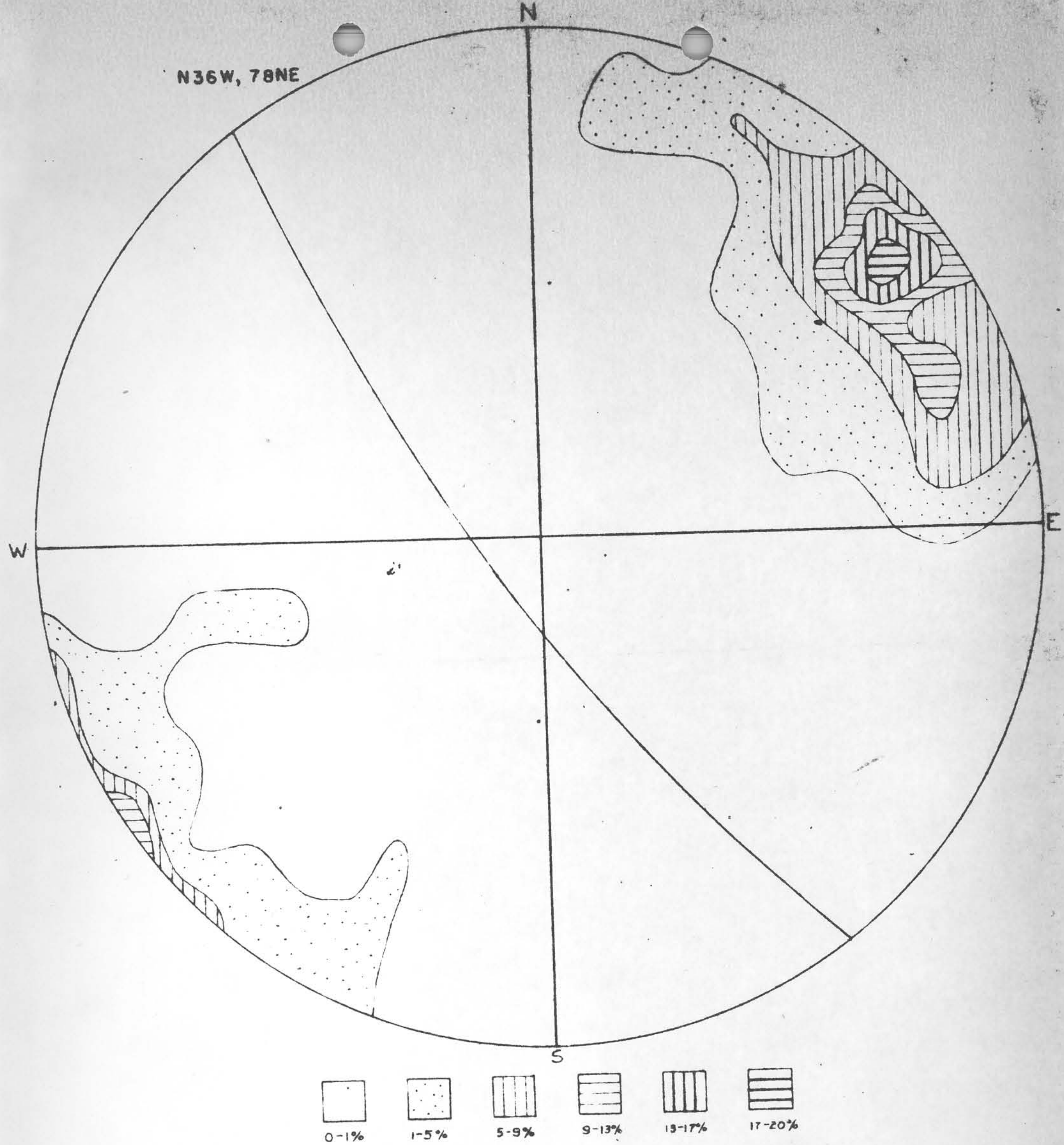
FIGURE 7



ATTITUDE OF JOINTS IN SLATE AND METAGABBRO

Alaska – Juneau mine, Alaska

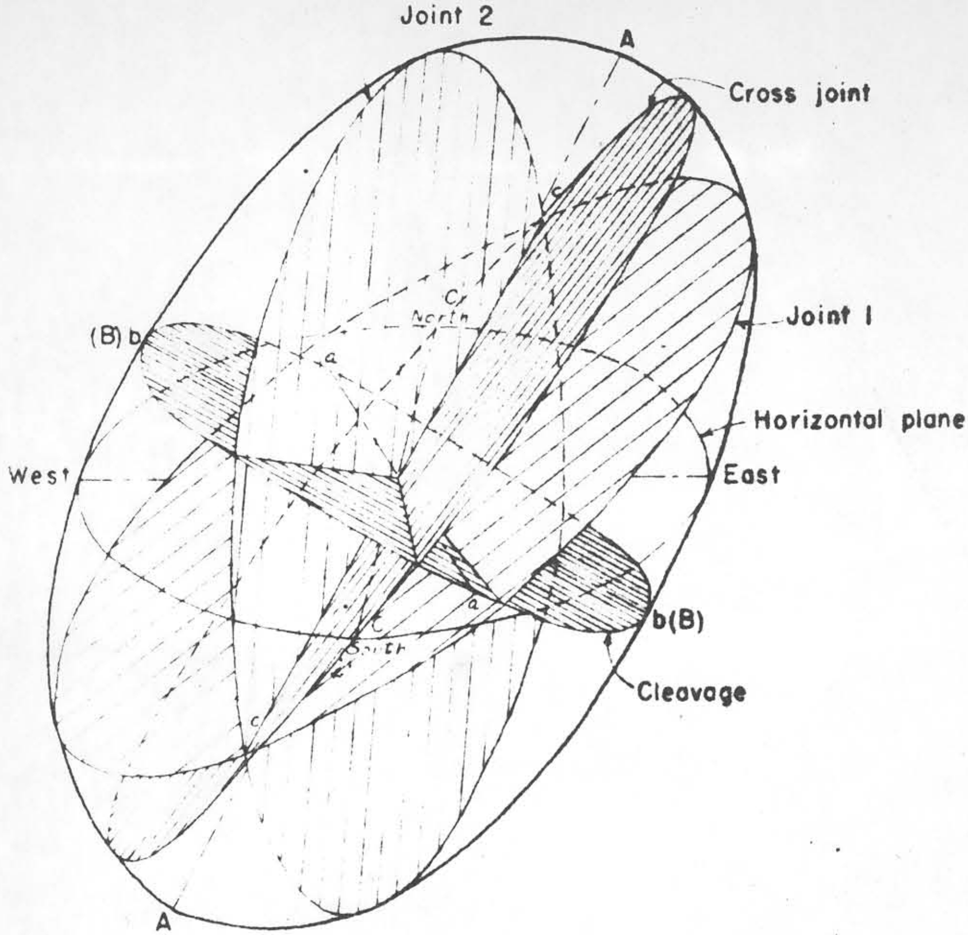
423 observations with poles plotted on upper hemisphere of spherical equal-area net



ATTITUDE OF VEINS
Alaska — Juneau mine, Alaska

87 observations with poles plotted on upper hemisphere of spherical equal-area net

FIGURE 9



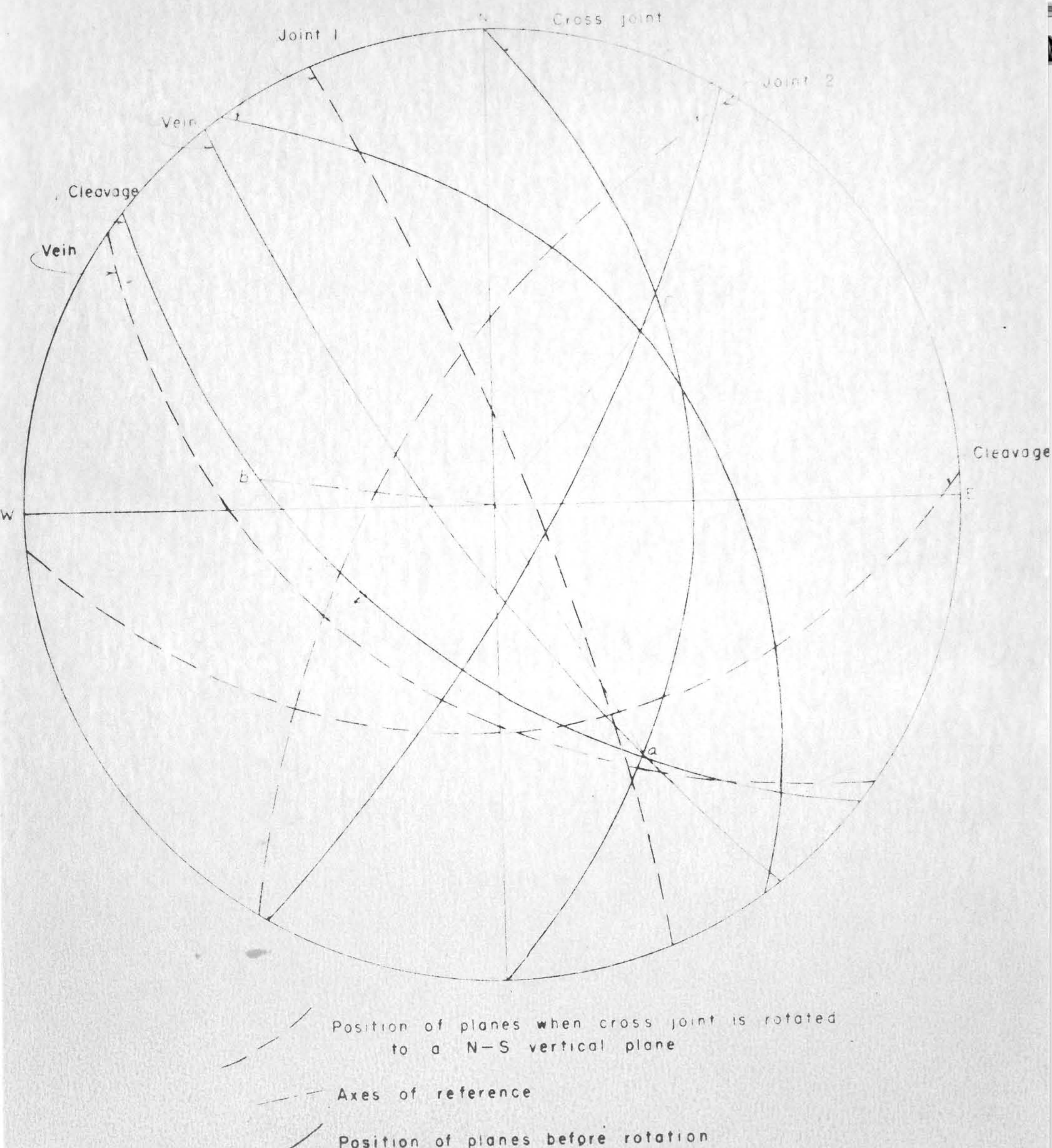
Component of maximum stress = C-C along north-south direction

Component of maximum relief = A-A

Component of maximum tectonic transport = a-a

ISOMETRIC DIAGRAM OF RELATIONSHIP OF CLEAVAGE AND JOINT PLANES TO ORIENTED ~~STRAIN~~ STRANGE ELLIPSOID

FIGURE 10



STEREOGRAPHIC PLOT OF CLEAVAGE, JOINTS, AND VEINS,
Alaska — Juneau mine, Alaska