Geology and Petrology of Two Stocks of Layered Gabbro in the Fairweather Range, Alaska

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By DARWIN L. ROSSMAN

CONTRIBUTIONS TO GENERAL GEOLOGY

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The geology and petrology of two layered gabbro stocks and a description of included ilmenite-bearing zones

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By Darwin L. Rossman

ABSTRACT

Two layered gabbroic stocks in the southern part of the Fairweather Range intrude a sequence of amphibole and biotite schists, which probably formed from a greenstone-slate unit of probable Mesozoic age. The greenstone-slate unit is unconformably overlain by sedimentary and volcanic rocks of Tertiary age.

The larger and northernmost stock, herein named the Crillon-La Perouse stock, is 17 miles long and 8 miles wide. The smaller, named the Astrolabe-De Langle stock, is largely concealed beneath the sea but is exposed for a distance of 8 miles along the coast.

Both stocks contain well-developed layers ranging in thickness from less than one inch to tens of feet; in each stock they form a structure similar in shape to a set of stacked saucers. The layering is discernible because of differences in grain size, proportion of minerals, or combinations of both. In places the layers show features analogous to those in sedimentary rocks, including graded bedding, crossbedding, slump structures, and ripple marks. The two stocks contain an exposed thickness of about 32,000 feet and 2,000 feet, respectively, of layered rock. Neither the bottom nor top is exposed in either stock.

The layered rock is mostly gabbro, but the proportions of plagioclase, pyroxene, and olivine vary in the individual layers. Neither the minerals nor the rocks show discernible trends in composition in the successions exposed in the two stocks. As far as can be determined, there is no interrelation in composition of the several mineral species in any layer, nor are differences in composition of the rock reflected in changes in the composition of the component minerals.

Both stocks contain ilmenite and small amounts of sulfide minerals, and in addition the Astrolabe-De Langle stock contains magnetite. The greatest concentration of ilmenite and sulfides found is in the contact zone on the northwestern end of the Crillon-La Perouse stock. One sample from the contact zone contains 47 percent ilmenite and 0.06 percent sulfides by weight. The layered rock itself also contains ilmenite, and one layer on the north end of the stock was found to contain 25 percent ilmenite by weight.

INTRODUCTION

Two layered gabbroic stocks intrude a sequence of amphibole and biotite schists in the southern end of the Fairweather Range, north of Cross Sound and west of Glacier Bay, in the northern part of southeastern Alaska (fig. 1). They lie within the Glacier Bay National Monument, about 110 miles west of Juneau. In this report the stock that includes Mount Crillon and Mount La Perouse is called the Crillon-La Perouse stock; the one that makes up the southern part of Mount De Langle and the Astrolabe Peninsula is called the Astrolabe-De Langle stock.

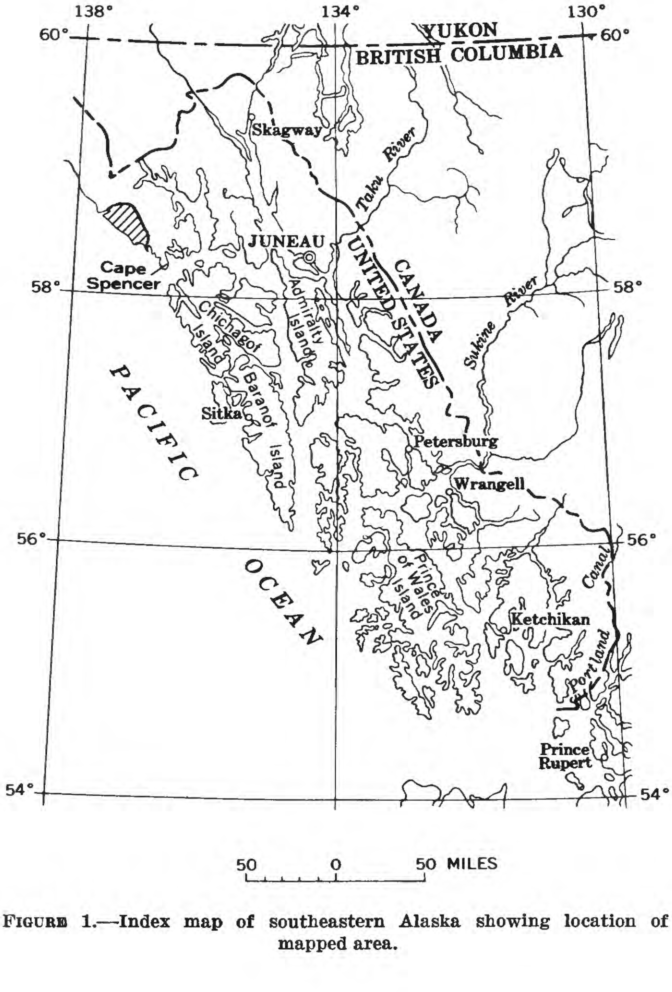

FIGURE 1.—Index map of southeastern Alaska showing location of mapped area.

PREVIOUS INVESTIGATIONS

In 1933 a Harvard-Dartmouth mountain climbing expedition under the leadership of Bradford Washburn found that Mount Crillon was composed of mafic layered igneous rock (R. G. Goldthwait, written communication, 1936). G. C. Kennedy, of the U.S. Geological Survey, made a reconnaissance up North Crillon Glacier in 1943 and wrote a short report on the area (Kennedy and Walton, 1946). The Wrights apparently discovered the Astrolabe-De Langle body some time in the early part of this century (F. E. Wright and C. W. Wright, written communication). The writer examined the gabbro on Astrolabe Peninsula and Boussole Head in 1946 and made a rapid reconnaissance of the southern part of the Fairweather Range in 1951, but no reports were written on these brief visits.

PRESENT INVESTIGATION

The present investigation was undertaken to study layered gabbroic stocks to appraise their potential for mineral resources, and at the same time carry out areal reconnaissance geologic mapping from Lituya Bay to Dixon Harbor and eastward to join mapping done previously in the eastern part of the Mount Fairweather quadrangle (Rossman, 1962).

The mapping of the area that includes the stocks was done in 1952 by the writer and James F. Seitz, assisted by Paul Bowen, Ian Hendrickson, Karl Stauffer, Rolland Reid, and Rolland Taber.

Equipment and personnel were transported from Juneau by wheeled and amphibian planes. A base camp was established near the coast 4.5 miles north of Icy Point on June 10, and other camps were established in other areas from time to time as the mapping progressed. The campsites are shown on plate 1, numbered according to the chronologic order in which they were occupied. The geologic party left the field August 30.

During the summer of 1953 the writer examined some of the layered rock exposed on the west side of Brady Glacier in the southeastern part of the Crillon-La Perouse stock, and he and George Plafker examined the contact in an area 4 miles northeast of Crillon Lake.

In 1956 the writer and Edward Green spent 10 days mapping in detail a small area on the south end of Astrolabe Peninsula in order to investigate the origin of the layers in the gabbro.

The geologic field mapping was done directly on aerial photographs. An attempt was made to collect a suite of specimens from the layered rock sequence that would be representative. As the specimens were taken, the stratigraphic interval represented by each specimen was estimated.

At places the rock was exposed only in cliff faces which could not be approached safely. At such places a suite of specimens was collected from loose rocks found below the cliffs. As the dip of the layers in the southern end of the Crillon-La Perouse stock exceeded 60° for most of the succession exposed, the talus below the cliffs could generally be assumed to have come from a "stratigraphic" interval of less than 1,000 feet. This same manner of collecting from detritus found below cliffs was used in a limited way on the north end of the stock.

The topographic map used in this report, scale 1:63,360 (pl. 1), was compiled by the writer from aerial photographs. The control for the map was obtained from points established along the coastline by the U.S. Coast and Geodetic Survey and from the known position and altitudes of the major mountain peaks. Subsidiary horizontal control was established by the radial-line method on aerial photographs, using steel templates. The photogrammetric work was done with a Mahan-type paper-print plotter; bridging was accomplished by adjustments on stereomodels repeatedly set up in the instrument until the best fit was obtained. The method is not completely accurate, particularly in measurement of altitude, and certain areas on models containing no points of known altitude may well be in error by several hundred feet. Nevertheless, the map gives a reasonably accurate representation of the position and shape of landforms, and the inaccuracies in altitude are spread over relatively large areas. The errors are thought to be too small to affect seriously the geologic-structure pattern.

GEOGRAPHY

The area shown on plate 1 includes a wide wave-cut coastal plain fronting the Pacific Ocean, a central ice-covered upland area containing the main part of the Fairweather Range, and the ice plateau of Brady Glacier.

The coastal plain extends from Baranof Island, across the mapped area, and discontinuously northward to at least as far as Cape Yakataga. Over most of this distance it is well developed, and in places is as much as 5 miles wide. The surface of the coastal plain is gently rolling with few hills rising more than 200 or 300 feet above the general level of the land surface. Locally on this plain are at least three major wave-cut terraces.

A narrow valley that is the surface expression of the Fairweather fault extends along the inland edge of the coastal plain from near Icy Point northwestward in a gentle curve to Lituya Glacier. The fault valley contains the two arms of Lituya Bay, Gilbert and Crillon Inlets, and the lower parts of Lituya Glacier and North and South Crillon Glaciers.

Northeast of the fault, the land surface rises steeply to form the small but rugged Fairweather Range. Within the mapped area the major peaks are Mount Crillon, Mount Dagelet, and Mount La Perouse. The south side of Mount La Perouse drops steeply to a glacier-filled basin; a high ridge lies south of the basin and its southern flank marks the south end of the Fairweather Range. Northwest of Mount La Perouse the high country is covered by an icefield that extends to Mount Crillon and is broken only by Mount Dagelet, which rises from the center to an altitude of 9,550 feet. The icefield ends on the northeast in a cliff that extends from east of Mount La Perouse to Mount Crillon.

The northwest side of Mount Crillon has been sculptured by the erosive action of North Crillon Glacier, and this side is now a sheer face more than 6,000 feet high. South Crillon Glacier has cut deeply into the western flank of Mount Crillon, making a cliff that is in places more than 3,000 feet high (pl. 1).

Brady Glacier lies between the Fairweather Range and the mountains to the east. It trends slightly west of north, and is about 38 miles long and 10 miles wide in its widest part. The southern end of the glacier no longer reaches sea level and is only moderately crevassed. In 1952 alder bushes several feet high were growing on the outwash plain in front of the glacier. The central part of Brady Glacier is nearly level. It receives some ice from Mount Bertha, Mount Crillon, and Mount La Perouse, but probably much of the ice in the glacier comes from the accumulation of snow on top of the glacier itself.

PLANTS AND ANIMALS

The animal life is abundant and varied, but is confined largely to areas containing vegetation. The animals known to exist in the area include: brown and black bears, wolves, wolverines, coyotes, mountain goats, marten, and red squirrels. Bird life is fairly abundant, and most of the shore birds that are common to the west coast of North America can be seen along the beaches at one time or another. The south side of Cenotaph Island is a rookery for sea gulls. The steep cliffs along the west side of Astrolabe Peninsula are used as nesting grounds by cormorants, puffins, and in a few places by kittiwakes.

The vegetation found in the low-lying areas around Lituya Bay is similar to that of other coastal areas in the northern part of southeastern Alaska. The forests contain spruce, hemlock, yellow cedar, and aspen trees, and many bushes such as alder, red and blue blueberries,

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cranberries, huckleberries, salmonberries, and devilsclub. In the beach areas are the common types of grasses, and locally loganberry and wild strawberry plants. Most of the low-lying coastal area is brushy and fairly difficult to traverse; however, forests of spruce and hemlock in those areas from which the glaciers have retreated within the last few hundred years are free of underbrush and windfalls. Yellow cedar does not exist within these areas, probably because of the relatively slow rate of establishment of these trees after glaciation, as compared to that of spruce and hemlock.

CULTURE

No person was permanently domiciled in the area in 1953, and works of man are few. A cabin stands on Cenotaph Island, another is located at Icy Point, and the remains of several exist near the beach in the area north of Lituya Bay. Manmade trails lie along the edge of the forest near the ocean beach both north and south of Lituya Bay. During the summer months a fish buyer regularly maintains a boat in Dixon Harbor, and fishermen commonly anchor their boats in Lituya Bay.

CLIMATE

The climate, as in the rest of southeastern Alaska, is humid and has an average monthly temperature at sea level varying from 35°–53°F. For several years the U.S. Weather Bureau has kept a record at Cape Spencer, which is about 12 miles south of Dixon Harbor; the data from this point are given in table 1.

TABLE 1.—*Weather record of Cape Spencer, Alaska, 1943–49*

[Courtesy of U.S. Weather Bureau]

Month	Mean monthly precipitation (inches)	Mean monthly temperature (Degrees Fahrenheit)
January	10. 04	34
February	5. 42	33
March	6. 90	37
April	5. 45	41
May	5. 81	46
June	5. 93	50
July	8. 84	53
August	8. 98	53
September	15. 81	51
October	18. 61	46
November	15. 58	38
December	10. 58	33

At Cape Spencer 65 percent of the days are cloudy, 25 percent partly cloudy, and 10 percent are clear. More than 70 percent of the days have 0.01 of an inch or more precipitation. In general these weather data are applicable to the area between Dixon Harbor and Lituya Bay. There are fewer cloudy days at Lituya Bay, but the total precipitation is probably about the same.

Between June and September the coastal area is often covered with dense fog. The top of the fog seldom extends above 7,000 feet, and the number of clear days and the number of days without precipitation are correspondingly increased above this altitude. The total annual precipitation at high altitudes is unknown, but undoubtedly it is high. Only in a short period during the middle of the summer can one be reasonably certain that snow will not fall at altitudes above 7,000 feet. During 1952 the last spring snow fell during early June, and the first fall snow fell on August 16. The temperature at high altitudes can drop below freezing at any time, but freezing temperatures are not common during June and July.

ACCESS

It is difficult to enter the southern part of the Fairweather Range. Landings by boat on the open ocean beach are impractical or impossible. The ocean in the vicinity of Lituya Bay may be exceedingly rough, owing to the strong tidal current flowing out of the bay on the outgoing tide. The terrain at the head of the bay does not afford a practical route into the high country, except up North Crillon Glacier which ends in virtually unclimbable cliffs.

The indentation in the coast immediately east of Icy Point affords some protection from the ocean swells, and landings can often be made there in calm weather; but a party landing here is confronted with moderately difficult problems when trying to reach the mountain range. A trail connects Icy Point and the large valley entering Palma Bay. The valley affords several long but practical routes to the lower part of the southern end and to the east side of the Fairweather Range. All the glaciers in this area are easily traversed. The high plateau between Mount La Perouse and Mount Crillon cannot be reached from this direction, however.

Another good way to reach the southern end of the range is to cross Brady Glacier from the head of Dundas Bay. This route was used by the writer's party in the summer of 1951.

The campsite where camp 1 was established in 1952 (pl. 1) is the best position from which to enter easily the southern end of the range. This campsite can be reached by using a plane capable of landing on the ocean beach or by walking along the beach from Icy Point. A trail was cut between the beach and the glacier, and another was made beyond the glacier to camp 5. There is no difficulty in reaching the layered rock body from campsite 5, but the traverse between camps 6 and 7 is somewhat more difficult. The ice is locally badly crevassed and several steep slopes must be climbed. It is probable that with changing ice conditions this part of the route would not always be open.

The most practical way to gain access to the high country between Mount Crillon and Mount La Perouse is to establish a base camp on the upper end of Crillon Lake by plane. From a base established here, an exceptionally easy route exists to the high basin southwest of Mount Crillon.

GEOLOGIC SETTING

The bedded rocks in the mapped area were subdivided by Mertie (1933, p. 125–133) into three units. The youngest unit, which is Tertiary in age, consists mainly of sedimentary rocks and minor amounts of volcanic rocks. These rocks unconformably overlie a greenstone-slate unit that is in fault contact with an amphibole and biotite schist sequence into which the two layered gabbroic stocks are intruded.

Several dioritic stocks crop out in the mapped area. They appear to be similar in lithology to some of the dioritic rocks that crop out near the mafic stocks on Chichagof and Yakobi Islands (Rossman, 1959a). In certain areas around the Crillon-La Perouse gabbroic stock the country rock is intruded by a network of coarse-grained silicic dikes; similar dikes, amphibole-bearing pegmatite dikes, and mafic dikes cut the gabbroic stocks.

BEDDED ROCKS

GREENSTONE-SLATE

The term "greenstone-slate" is applied to the group of rocks that unconformably underlie the sedimentary rocks of Tertiary age; although this group is composed primarily of interbedded greenstone and slate, it contains other varieties of rock, such as limestone. The greenstone- slate unit crops out on the southwest side of the large fault that trends across the head of Lituya Bay (Fairweather fault). Much of the rock has undergone intense deformation, and because the rock is inherently structurally weak it has flowed so that the greenstone and slate are now intimately intermixed.

The greenstone-slate sequence was described by Mertie (1933, p. 126–127), who thought that because similar rocks of Carboniferous and Mesozoic age are widely distributed elsewhere in southern and southeastern Alaska, the greenstone-slate sequence might belong in this age group. He felt that the presence of limestone in the sequence favors its assignment to the Carboniferous or Triassic rather than to the Jurassic or Cretaceous, but he was careful to point out that such a correlation was based merely upon lithologic considerations. The rocks in the mapped area are very similar in lithology to some of the rocks found on Chichagof Island, which are believed to be of Triassic or Jurassic age; the present writer believes that the greenstone-slate sequence is correlative with the Triassic or Jurassic rocks found on Chichagof Island.

AMPHIBOLE AND BIOTITE SCHISTS

The amphibole and biotite schists occupy a belt about 1¼ miles wide along the southwest side of the Crillon-La Perouse stock and compose most of the bedded rock in the area immediately north of North Crillon Glacier. Similar schists which presumably are correlative crop out south of the Crillon-La Perouse stock. Throughout most of the area the bedding in the schists strikes northwest and dips steeply to the northeast. The amphibole and biotite schists are believed to be genetically related and the metamorphic equivalents of the greenstone-slate sequence. Obviously the schists are in fault contact with the greenstone-slate sequence, and it is believed that fault movement has brought together parts of the same sequence that were originally widely separated and metamorphosed to different degrees.

The amphibole schist is a medium- to fine-grained rock. In outcrop it is typically dark green or gray. The amphibole, which is commonly hornblende, is the most abundant mineral. The amphibole crystals generally show a strong lineation. The amphibole schist near the Crillon-La Perouse stock is somewhat coarse grained and contains larger grains of feldspar than does the rock farther away from the stock. Where the rock is highly recrystallized the schistosity gives way to gneissic structure. Near its contact with the igneous rock, the schist is partly assimilated and consists of thin lenticular amphibole-bearing masses surrounded by material that is made up largely of feldspar. At many places near the contact the amphibole schists have been stained green by copper minerals.

The biotite schist is a medium- to fine-grained rock. In areas that have recently been uncovered from beneath snow and ice, the rock is stained rust red and from a distance is scarcely distinguishable from the layered igneous rock. In more deeply weathered outcrops, where leaching and chemical weathering have taken place, the rock is light gray. In general, small structures such as drag folds are more common in the biotite schist than they are in the amphibole schist. The rock has a pronounced foliation and a less well-developed lineation. The rock is apparently highly susceptible to recrystallization, and within a distance of 1 mile from the Crillon-La Perouse stock the biotite schist becomes coarse grained. Near the stock the biotite schist contains andalusite, or, less commonly, staurolite. Generally these minerals are accompanied by small but abundant garnets.

The amphibole and biotite schists are too highly metamorphosed to contain recognizable fossils, and any conclusions regarding the age of the rocks must be drawn from their similarity and relation to other rock units whose age is better known. The schists can be traced southeastward from the Fairweather Range into an area where they are less metamorphosed. The biotite schist can be traced to the vicinity of Graves Harbor and Torch Bay, where it grades into a succession composed of rock similar to the graywacke unit on Chichagof Island. The amphibole schist can be traced southeastward to the peninsula between Torch Bay and Dixon Harbor, where it disappears beneath the sea; it is similar to rocks found in the greenstone and schist units as mapped by Reed and Coats on Chichagof Island (Reed and Coats, 1941). All these units on Chichagof Island are believed to be Mesozoic in age.

UNDIFFERENTIATED BEDDED ROCKS OF TERTIARY AGE

The bedded rocks of Tertiary age consist predominantly of siltstone, conglomerate, and pebble-bearing siltstone. The lower part of the succession contains a few coal beds, and locally the sedimentary rocks are interstratified with volcanic rocks. They are strongly folded and cut by faults.

The youngest rocks exposed, which are believed from fossil evidence to be Pliocene or Pleistocene, are only slightly consolidated and appear to consist mainly of glacial silt. They crop out near the coast immediately northwest of La Perouse Glacier. These rocks have been folded, and most have a steep southward dip; in places they are overturned. The siltstone contains a considerable amount of the mineral bronzite—an orthorhombic variety of pyroxene—which is identical to that found in the Crillon-La Perouse stock, and may have come from the stock. If this is true, then the stock was exposed to erosion at the time the silts were being deposited, and the extensive folding which the bedded rock has undergone must have taken place after the intrusion of the layered igneous rock.

SURFICIAL DEPOSITS

Surficial deposits of Quaternary age in the mapped area consist of glacial moraine, valley fill composed largely of glacial debris, and sand on the ocean beach.

IGNEOUS ROCKS

LAYERED GABBRO

LOCATION AND GENERAL RELATIONS

Several layered gabbroic stocks crop out along the west coast of southeastern Alaska. These fall in a remarkably narrow and straight northwestward-trending zone (fig. 2). The northernmost known body crops out somewhere in the mountains flanking the upper part of Fairweather Glacier. The body has never been seen and its existence is known only because a large part of the moraine encircling Fairweather Glacier at Cape Fairweather contains layered gabbro, which is similar in composition and appearance to the layered gabbro found farther south.

The other layered gabbroic stocks from north to south are the Crillon-La Perouse, the Astrolabe-De Langle, the Bohemia Basin, several unnamed stocks on Yakobi Island, and one at Mirror Harbor on Chichagof Island. It is not known if all the gabbroic stocks on Yakobi Island are layered, but they have the same mineral components and texture as the layered stocks. They are known to be of approximately the same age as the layered gabbroic stocks and are believed to be genetically related. All the layered gabbros intrude bedded rocks believed to be of Mesozoic age.

The Crillon-La Perouse stock is elliptical in plan and is about 17 miles long and 7 to 8 miles wide. Its long axis trends northwestward. The Astrolabe-De Langle stock is exposed for a distance of 8 miles along the coast, but most of the body is concealed by the sea. Its known outline suggests that the shape may be elliptical in plan like that of the Crillon-La Perouse stock.

Both the Crillon-La Perouse and the Astrolabe-De Langle stocks were intruded into the amphibole and biotite schist units. Vertical sections of the contact several thousand feet high are visible at places along the east and west side of the Crillon-La Perouse stock (fig. 4) and smaller vertical sections are exposed at many other places. From a distance most of the exposures of the contact give an impression of a distinct and abrupt change in structure and rock type. Upon closer inspection, the contact can be seen to be gradational; it consists of a zone as much as 100 feet wide containing rock that apparently is a mixture of the gabbroic rock and schists that were partly or com-

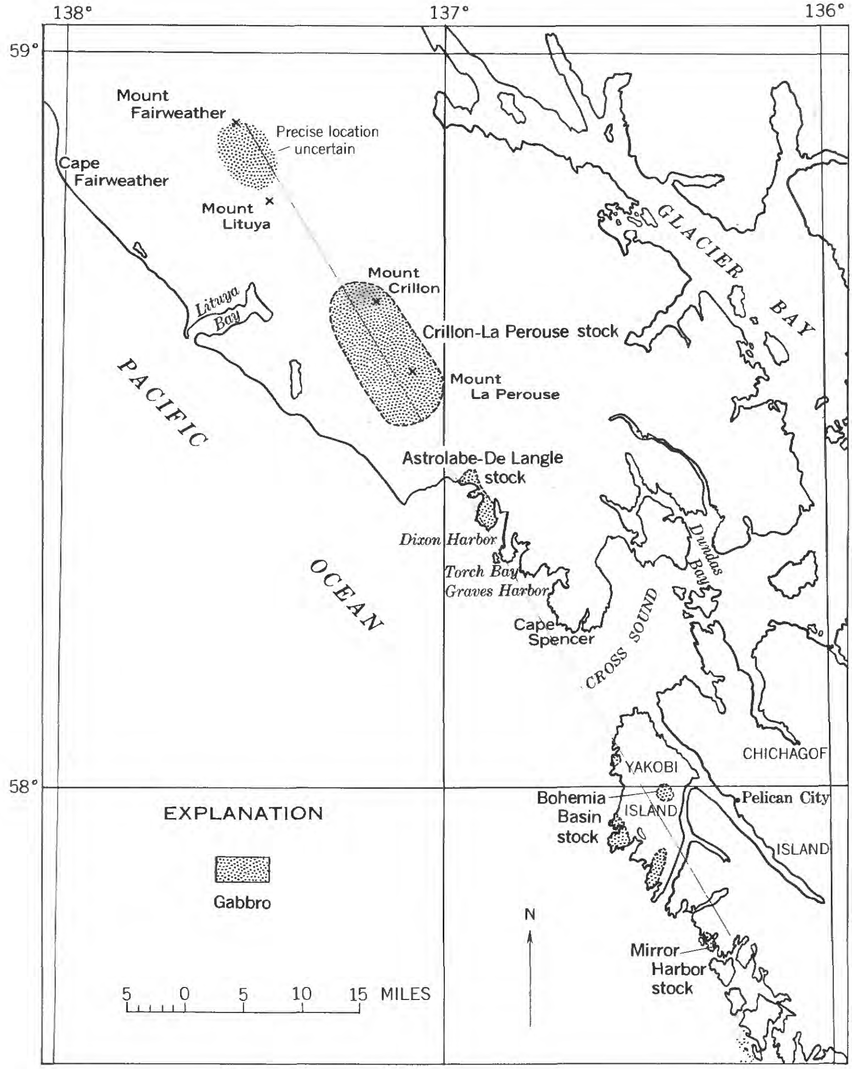

FIGURE 2.—Sketch map showing linear distribution of the gabbroic stocks in the southern end of Fairweather Range and in the western part of Yakobi and Chichagof Islands.

pletely assimilated by the gabbroic magma. The schist has been thoroughly recrystallized around both the Crillon-La Perouse and the Astrolabe-De Langle stocks; and the effects of recrystallization, discernible in the rock for several miles away from the contact, become progressively more pronounced toward the stocks. Near the contact, the schist contains alamandine garnet, andalusite, staurolite, hornblende, biotite, kyanite, magnetite, ilmenite, and sulfides. The minerals found at any one locality do not include all those listed above, nor are the mineral suites near the contacts of the two stocks the same. Near the Astrolabe-De Langle stock the recrystallized rock commonly consists mainly of large hornblende and plagioclase crystals, and locally contains titaniferous magnetite. Undoubtedly the differences in mineral suites at different localities along the contacts are the result of differences in composition of the intruded rocks. Generally the igneous rock near the contact has an uneven texture and contains inclusions in all stages of assimilation.

Most of the Crillon-La Perouse stock is covered by ice and snow; nevertheless, the stock is exposed sufficiently well to give a good idea of the internal structure and shape of its western half. An excellent transverse section of the layered stock is exposed in almost continuous outcrop on the southeast flank of Mount La Perouse. A nearly complete longitudinal section is exposed on the cliff face that extends from the east side of Mount La Perouse to the east side of Mount Crillon. Other extensive rock successions are exposed on the walls of the valleys of North and South Crillon Glaciers, in the cliff faces of Mount Dagelet, and on the flanks of the unnamed mountain peaks in the central part and southern end of the layered rock body. These large exposures show clearly and unmistakably that the layers form a single huge elliptical basin-shaped structure. The dip of the layers in the south end of the stock is much steeper than the dip of the layers at the north end. At the south end the greatest single succession of layered rock is exposed. The total thickness between the lowermost and uppermost rocks exposed is nearly 32,000 feet. Although an estimate of the downward extent of the body cannot be made, it is inferred from the general size, shape, and internal structure that many more thousands of feet of layered rock exist below the lowest layers presently exposed.

The gabbroic rocks in the uppermost part of the layered succession, which is exposed in the peak of Mount La Perouse, contain more sulfide, graphite, apatite, and fragments of partly assimilated rocks probably not of igneous origin than do the layered rocks from other parts of the stock. Moreover, the rock is more altered than is the gabbro in other parts of the stock. These features suggest that the uppermost layered rocks may have been in relatively close proximity to the roof or side of the original magma chamber.

Because the structure of the Crillon-La Perouse stock is uniform, continuous, clearly discernible, and uncomplicated by later movement,

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it is thought that no necks or other structures exist within it, and that multiple injection did not take place. The only place where such structures could exist and remain undetected would be along the east side of the stock beneath Brady Glacier.

About 2,000 feet of layered rocks are exposed in the Astrolabe-De Langle stock. From the apparent offset in the general position of the eastern contact (pl. 1), it is inferred that the stock has been cut by faults having several thousand feet of horizontal displacement. Near the northeast contact some of the layers dip to the east toward the contact. It is not known whether this dip is an original structure or was formed by later movement after the rock had partly solidified.

It is the writer's opinion that the original form of the layering in both layered intrusive bodies was about like that of a shallow basin (fig. 3). The layers at the margin probably had an original inward dip that was somewhat less than 45°. When viewed from a distance great enough that the overall structure of the stock is apparent, the layers are seen to be truncated at the contact. At close range, however, the relation of the layers to the contact is commonly less easily interpreted and about all that can be determined is that the layers grade into massive rock within one or two hundred feet from the contact. The contact was probably either vertical or dipped steeply either inward or outward. In the central part of the stocks the layers may have been nearly flat. If the original shape of the Crillon-La Perouse stock is as outlined above, then it has subsequently been deformed on the southeastern end into a deeper synclinal basin.

DESCRIPTION OF LAYERING

The layering in both the Crillon-La Perouse and the Astrolabe-De Langle stocks is well developed throughout all their exposed parts. The layers are so distinct that they can be seen from a score of miles away (fig. 4). At places they are visible on standard quality 1:40,000-scale aerial photographs. Both the Crillon-La Perouse and the Astrolabe-De Langle stocks are composed of gabbro; the common rock-forming minerals are plagioclase, orthorhombic and monoclinic pyroxene, and olivine. These minerals occur in different proportions in the different layers, and it is this variation in proportion or a variation in grain size from one layer to the next that forms the layering (figs. 5, 6). The layers range in thickness from a fraction of an inch to as much as 50 feet, but layers 2 inches to 5 feet thick are the most common.

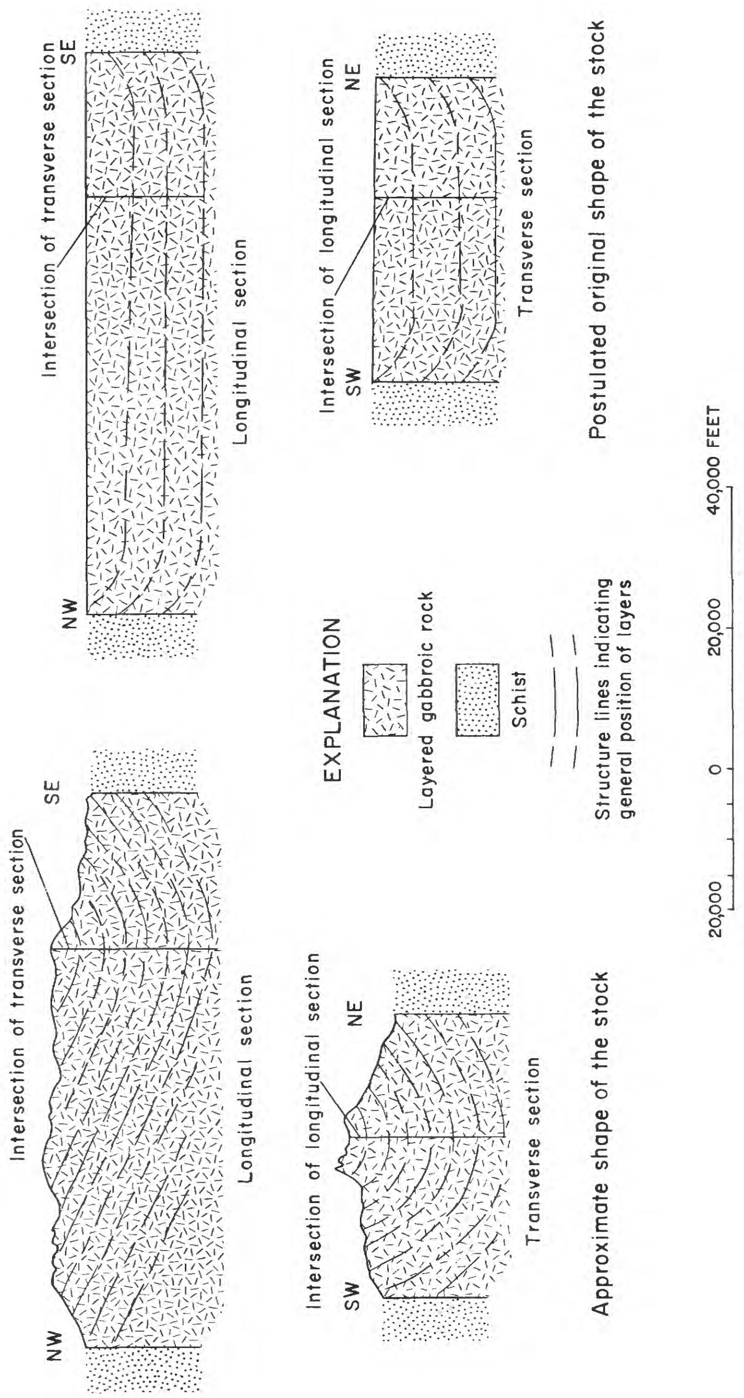


FIGURE 3.—Cross sections showing present and postulated original structure of the Crillon-La Perouse stock.

FIGURE 4.—A cliff about 2,000 feet high on the northwest shoulder of Mount Crillon showing structural features in the igneous rock. The layers in this area are somewhat more discontinuous than is common in other parts of the stock.

Many of the layers show a strong continuity over considerable distances. On the southern end of the Crillon-La Perouse stock, layers as thin as 1 foot can be traced for the full distance of an outcrop, which is in places a distance of more than 1 mile, and undoubtedly some layers extend for even greater distances. The writer has not observed the layers at the north end from the ground, but zones composed of groups of layers can be seen, both on photographs and from the air, that extend for at least 3 miles along the west and north faces of Mount Crillon. At least 12 such zones are visible. Strong persistence of layers is not universal throughout the stock as marked changes in thickness or a complete pinching out of layers can be observed in certain outcrops (fig. 7). Detailed mapping at the Astrolabe-De Langle stock also showed that although many layers are continuous for hundreds, if not thousands, of feet, other layers are lenticular. Some layers were found that were not more than 40 feet long, but were as much as 5 feet thick at their thickest point.

FIGURE 5.—Layering typical of much of the rock. The dark irregular-shaped zone through the center of the illustration is due to spalling of the rock rather than to a different rock type. About 5 feet of succession shown.

FIGURE 6.—Graded layering, top of succession to right.

LAYERING IN THE CRILLON-LA PEROUSE STOCK

FIGURE 7.—Layered rock from the south end of the Crillon-La Perouse stock. The marginal contact is about one-half a mile to the left of the outcrop shown. Note thinning and pinching out of layers in the direction of contact. The layers shown here are not so continuous as those near the center of the stock.

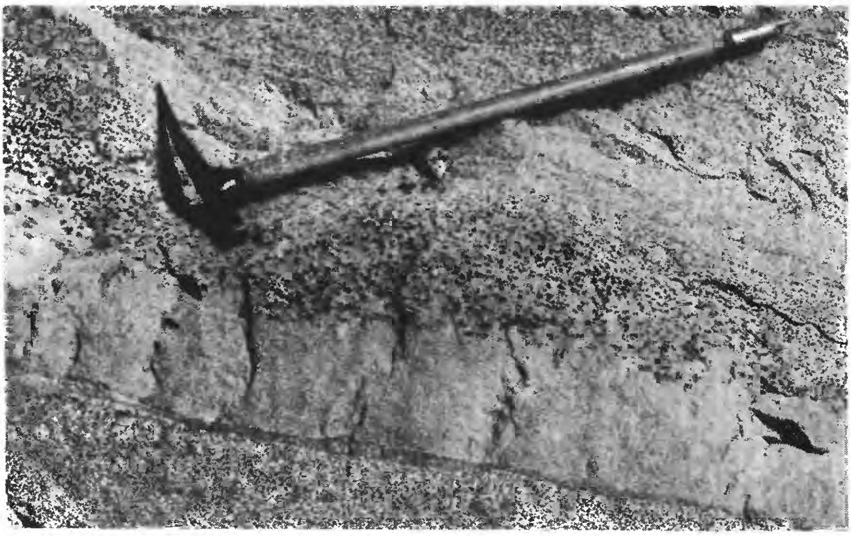


FIGURE 8.—Layering in rock on the south end of the Crillon-La Perouse stock. Some of the features shown are probably brought about by crystal settling. Note that below pick the crystals get smaller upward. This type of grain-size change is most common, but layers exist in which the crystals get larger upward. Pick handle is 26 inches long.

STRUCTURAL FEATURES IN THE LAYERED ROCK AWAY FROM THE MARGINS OF THE STOCKS

Generally the contact between layers is straight and sharply defined, and one has no difficulty in deciding on what constitutes a single layer. In some areas near the margins of the stocks, particularly in the Astrolabe-De Langle body, the contacts between layers are, on a small scale, wavy or extremely irregular.

Most of the rock within the layers has a discernible fabric in which the elongate or flat minerals lie with their long axis or flat sides parallel to the plane of the layering. Generally the rock within a layer is uniform in grain size, fabric, and proportion of included minerals; but in a few layers both the proportion of the different minerals and the grain size vary.

Rarely the contact between layers is a plane of weakness and the rock will break along the contact, exposing the surface of a layer. Of the several such exposures that have been found, most show a gently undulating surface. Some show rounded protuberances, about 4 inches in diameter and 1 inch high, thickly scattered over the surface. These generally are spaced on centers that are about equal to three times the diameter of the protuberances, but as far as can be seen they are not alined in any systematic way.

At one place on the southwest coast of Astrolabe Peninsula there is an exposure of the surface of a layer that measures about 15 by 20 feet. The surface contains structures resembling incomplete wave ripple marks (Shrock, 1948, p. 122) that are low, rounded, and symmetrical. The ridges generally are about 5 inches wide and separated one from another by a distance two to three times the width of the ridge. They are continuous for a distance of about 2 feet and commonly are interconnected by low saddles. Generally they show no tendency to lie along the same line, but their long axes show a vague preferred northeast trend.

At two places in the Astrolabe-De Langle stock, structures analogous to crossbedding were found. The layers, as well as sublayers within layers, may swell and pinch like beds in current-deposited sands. Rarely one finds layers truncated at low angles, suggesting current erosion. The crystals appear to be the counterpart of the rock and mineral grains in sedimentary rocks. Size sorting is common, especially in the Crillon-La Perouse stock in areas well away from the margins. Structures similar to graded beds, in which the largest crystals occur at the base of the layers, are fairly common (fig. 8); rarely the reverse is also observed. The grading in grain size seems to be restricted to the ferromagnesian minerals.

One of the most unusual forms of layering was found only at a few places near the contact in the Astrolabe-De Langle stock. The layers are made up of rounded masses, 0.5 inch to 3 feet in diameter, that are all composed of the same rock type (figs. 9, 10) and are embedded in material having essentially the same composition and texture as the rounded masses. This makes the masses indistinct or invisible, except on unusually well-exposed and favorably weathered surfaces. A few of the rounded masses show faint relict layering, indicating that they were derived from partly solidified layered material. The rounding suggests that the masses were moved sufficiently to become somewhat abraded. Similar rounded masses are also fairly common in otherwise normal appearing layers. These masses are most commonly observed just above the base of a layer where the rounded masses rest on material that is coarser grained and darker, and thus contrasts strongly with them. The upper sides of these rounded masses are commonly indistinguishable from the groundmass.

Features analogous to slump structures are present in the Astrolabe-De Langle stock in areas near the contact where the layers have an appreciable slope. Small slump structures consist of layers or parts of layers buckled into small asymmetrical folds, or of masses of material that slid to form small mounds of irregular size and shape. The slumping of entire layers, as well as of just the top parts of layers, appears to have occurred. In places the upper parts of layers have been torn up, so that they contain small humps and irregularly shaped hollows. The material torn from its original position must have had some coherence, because locally a thin sheet of the surface material has been torn away from the underlying mass at one edge only and folded back bottom side up over the adjacent surface of the layer. Many of these structures are strikingly similar to those illustrated by Kuenen in his laboratory studies on density currents (Kuenen and Migliorini, 1950).

At places large blocks of layered igneous rock appear to have been torn from their original resting place and to have slid downslope toward the central part of the basin. On the ridge between North and South Crillon Glaciers, a wedge-shaped block of layered gabbro several thousand feet long and probably 500 feet thick appears to have slipped and overridden some of the same layers that compose the block. The amount of movement of this block must be several hundred feet.

The Astrolabe-De Langle stock contains a few angular xenolithic blocks that apparently fell into the magma chamber. Some of these are as much as 4 feet in diameter. They appear to have depressed and partly penetrated the layers on which they rest, and overlying layers

FIGURE 9.—Structural features thought to be caused by movement—a layer composed of rounded masses of gabbro has been retouched to outline some of these rounded masses visible in photograph. Boulder near contact of Astrólabe-De Langle stock.

FIGURE 10.—Structural features thought to be caused by movement—the upper part of the lowest layer (immediately below the dark-gray layer) is composed largely of rounded but elongate masses of gabbro similar to that shown in figure 9. Boulder near contact of Astrolabe-De Langle stock.

are humped up over the top of the blocks. Generally the structural effects below the block are discernible for a distance about equal to one half its diameter, and above the block the layers show traces of a rounded form for a distance equal to $1\frac{1}{2}$ times the diameter of the block.

PETROGRAPHY

Most of the petrographic work done for this report was aimed primarily at relating the petrographic characteristics of the several mineral species of the gabbro to their relative "stratigraphic" position within the layered rock successions.

The crystals in the layered rock range from 0.1 mm to 1 cm in diameter, but they are mostly from 0.5 to 4 mm in diameter. The rock is dark grayish green to light olive gray on weathered and leached surfaces, and dark yellowish brown to dark gray on fresh surfaces. The color of the layers depends on the proportions of minerals, those layers containing large amounts of ilmenite being the darkest, generally a dark gray, and those containing a high proportion of feldspar being the lightest, generally a medium gray. The common rock-forming minerals are plagioclase, orthorhombic and monoclinic pyroxene, and olivine; they are, as a rule, unaltered. Ilmenite is common in the Crillon-La Perouse stock, and magnetite and ilmenite make up as much as 16 percent of some layers in the Astrolabe-De Langle stock. Apatite, sulfide minerals, and graphite are present in small amounts.

Textures in the rocks range from xenomorphic granular (in which none of the mineral grains developed crystal faces) to hypautomorphic granular (in which some of the mineral grains developed crystal outlines and some did not). In sections cut at an angle to the plane of the layering, a faint to moderate preferred dimensional fabric commonly is discernible. In some rocks, such as shown in figure 11, the plagioclase crystals have crystal outlines but the edges between faces are rounded. The spaces between these subhedral crystals are filled by ferromagnesian minerals. This suggests that the plagioclase formed first, probably as settled crystals with the ferromagnesian minerals crystallizing in place. More commonly the rock texture is characterized by somewhat rounded grains of ferromagnesian minerals that have some suggestion of crystal faces. These textures are present in figures 11 and 12. In places the ferromagnesian mineral grains have sharp acute-angle corners and concave or scalloped sides. These minerals also are believed to represent fillings of the interstitial area between settled crystals. In many thin sections examined, rounded or subhedral grains of orthopyroxene or olivine were observed surrounded by crystals of clinopyroxene (fig. 11). Where this relationship exists, generally the encircling clinopyroxene is interstitial to adjacent grains. Normally olivine is present only as rounded grains; it may be found enclosed in crystals of any of the other rock-forming minerals. Figures 11 and 12 illustrate textures of typical layered igneous rock. The same types of textures are present in layered gabbros and norites in other parts of the world. The layered rock of the Great Dyke of Rhodesia (Lightfoot, 1941) and in the Sierra Leone batholith in Africa (Dixey, 1922) have textures similar to those found in the layered rocks under discussion.

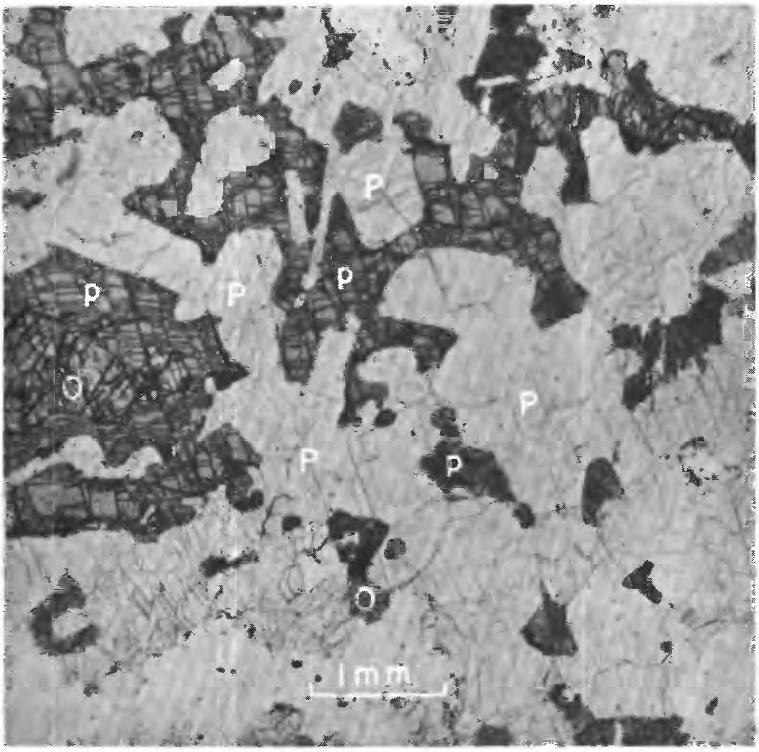


FIGURE 11.—Photomicrograph showing textures in typical layered igneous rocks. Olivine crystals (O) are surrounded by pyroxene (p), and these crystals are in close contact with a slightly rounded but euhedral plagioclase (P). This suggests that both the plagioclase and olivine are older than the pyroxene. Probably the former two are primary crystals, and the pyroxene crystallized from either a slightly later phase in the melt or from an interstitial liquid.

The rock in thin section shows little evidence of deformation, although pyroxene, plagioclase, and, to a lesser extent, olivine show fractures and undulatory extinction.

Because the gabbro is layered and the layers are formed through variations in proportions of the included minerals, it is obvious that

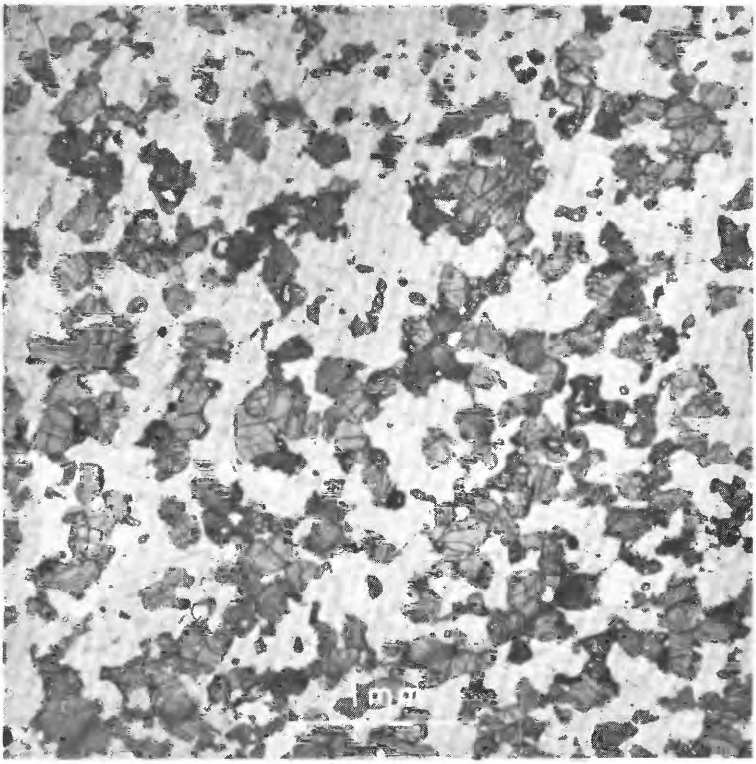


FIGURE 12.—Photomicrograph showing texture typical of the layered norite.

the rock ranges widely in composition, even within a single layer. Thus, it proved impossible to sample sufficiently large parts of the layered complex to obtain a sample which would reliably reflect the average composition of the complex or even the average composition of any large part of it. Nevertheless, four samples were selected for analysis which were judged from their general appearance to be intermediate in composition. These analyses and norms have been included (table 2) to show the general composition of the rock, but they do not necessarily represent the average rock.

Optical data indicate that the bulk of the plagioclase in both stocks has an anorthite content between 55 and 70 percent. Table 3 gives the composition and the optical properties of one plagioclase. In thin section, most of the plagioclase is seen to be clear and sharply twinned. Typically the twin planes are fairly evenly spaced and moderate to coarse in thickness. Twinning in accordance with the albite, carlsbad, and pericline laws has been recognized. Commonly the twin lamellae extend through the crystals and show no change in

TABLE 2.—*Chemical analyses of four rock samples from the Astrolabe-De Langle stock*

[Samples analyzed by methods similar to those described in U.S. Geol. Survey Bull. 1036-C. Analysts Paul L. D. Elmore, Katrine E. White, Samuel D. Botts]

	52ARm a 17	52ARm g 36	52ARm e 40	52ARm d 40
	Analyses			
SiO_2	48.2	48.4	50.8	48.4
Al_2O_3	17.4	17.4	21.8	17.9
Fe_2O_3	2.6	2.2	2.0	1.8
FeO	6.1	6.6	3.0	6.2
CaO	12.0	12.0	13.4	12.4
MgO	9.3	9.4	5.2	10.0
Na_2O	2.5	2.5	3.0	2.0
K_2O	.07	.05	.06	.06
MnO	.14	.14	.09	.12
TiO_2	.60	.60	.57	.38
P_2O_5	.02	.02	.01	.01
H_2O	.87	.24	.28	.29
CO_2	<.05	<.05	<.05	<.05
Total	99.85	99.60	100.26	99.61
	Norms			
Apatite	0.028	0.028	0.0035	0.0035
Ilmenite	.792	.82	.82	.54
Magnetite	2.58	2.26	.45	3.81
Orthoclase	.035	.025	.03	.035
Albite	21.25	21.99	2.75	1.80
Anorthite	34.25	35.99	60.70	48.78
Wollastonite	9.74	8.92	3.22	5.26
Enstatite	9.78	11.02	14.84	27.84
Ferrosilite	2.56	3.36	3.42	4.08
Forsterite	10.92	10.80		
Fayalite	2.91	3.27		
Quartz			11.98	6.05
H_2O	5.21	1.52	1.78	1.802
Total	100.055	100.00	99.99	100.00

size or degree of development at the edge. However, in some crystals the twin lamellae terminate at a uniform distance from the edge. The opposite effect also occurs, and some twins have formed along the margins and extend only a short distance into the crystals. Some grains appear to have undergone more than one age of twinning. Locally, fractures in the plagioclase have either interfered with the development of the twins or have destroyed them.

Alteration of the plagioclase is slight, but the grains contain inclusions, some of which appear to be rounded grains of minerals similar to the rock-forming ferromagnesian minerals. Commonly the plagioclase contains needle-shaped crystals of an opaque mineral. In

TABLE 3.—*Composition and optical properties of plagioclase from the Astrolabe-De Langle stock*

[Specimen 52ARm d 40. Analysis done by rapid method of Maxwell K. Carron, U.S. Geological Survey]

	Weight percent	Equivalent weight	Number of— Oxygen atoms	Number of— Cations	Number of— Atoms
SiO_2	50.76	0.8452	1.6904	0.8452	Si =2.31 3.99; 17 percent SiO_2
Al_2O_3	31.05	.3073	.9219	.6146	Al=1.68 deficiency
Fe_2O_3	.14	.0009	.0027	.0018	Fe^{+3}=.005 } Impurities
FeO	.24	.0033	.0033	.0033	Fe^{+2}=.009 } Impurities
MgO	.09	.0022	.0022	.0022	Mg =.006 } Impurities
TiO_2	Trace				
CaO	13.68	.2400	.2400	.2400	Ca=.66
Na_2O	3.77	.0608	.0608	.1216	Na=.33
K_2O	.08	.00008	.00008	.00016	K=.004
MnO	.00				
	99.81		2.92138		O=8.00

(Na Ca) Al Si_3O_8 $\frac{8}{2.92138}$=2.7384

Formula: $Na_{33.5}$ $Ca_{66.5}$ Al Si_3 O_8

Optical data:

n_x	n_y	n_z
1.5613	1.5646±	1.5697
1.5613	1.5645±	1.5697
1.5613		1.5692
		1.5697
		1.5706
Average 1.5613±0.0003	1.5645 (accuracy low)	1.5698±0.0003

$n_z - n_x$ (average) =0.0085

Index determined by immersion of grains in oil of known index, oriented on universal stage and match attained with variable monochrometer. Index of oil checked after use on universal stage with Abbé refractometer.

the Astrolabe-De Langle stock the plagioclase from the coarser grained layers contains the most inclusions.

Zoning in the plagioclase is virtually absent. No oscillatory zoning was found in the several hundred thin sections examined—although it was searched for carefully—nor was any evidence of relict zoning found. Progressive zoning is rare, and where observed it seems to have formed by reaction of the plagioclase with the surrounding grains; to the writer it appears not to be zoning in the normal sense at all. Rarely the plagioclase exhibits rapakivi-like borders of plagioclase on plagioclase. Accurate determination of the index of refraction of the plagioclase in about 50 samples by use of a frequency-distribution technique and variable monochromatic light, shows that the plagioclase varies less than ±0.0003 in index in any one sample.

The twin-zone relationship in plagioclase that is generally believed to be the normal pattern in plutonic rocks (Emmons and Mann, 1953) apparently has not developed in the layered gabbroic rock under investigation. The conclusion that zoning is a prerequisite for twinning (Emmons and Mann, 1953, p. 54) either must not hold for these layered rocks or the zoning has been obliterated.

Clinopyroxene is present both as rounded grains and irregularly shaped crystals. The rounded grains are believed to be settled crystals, and the irregularly shaped crystals probably formed later in the spaces between the earlier formed settled mineral grains. The interstitial crystals commonly are poikilitic, and they may be several times larger than the primary crystals.

Reaction rims composed of clinopyroxene locally have grown around crystals of orthopyroxene and olivine. In certain areas, most commonly near dikes and fractures, the borders of the pyroxene crystals have rims of chlorite.

Nearly all the pyroxene in the rock of the layered succession contains abundant well-developed lamellae. Other investigators who have studied pyroxene from similar rocks believe that the lamellae are devolped by exsolution that takes place as the melt cools and some crystal phases become stable while other already formed become unstable (Poldervaart and Hess, 1951). If cooling is sufficiently slow and if the melt remains accessible to the crystals, complete transformation from one phase to another can take place. Some evidence exists that indicates lamellae formed by exsolution are developed to different degrees in the different species of pyroxene because of their inherently different molecular structure, provided other factors remain equal. It appears likely that lamellae are more widely spaced and thicker in minerals where the ions necessary to form the lamellae can migrate parallel to the SiO_4 chains instead of across them. Thus, exsolved lamellae along (001) should be thicker and farther apart than would lamellae formed along (100). A comparison between the width of the lamellae and the distance between lamellae in the clinopyroxene and orthopyroxene from the Crillon-La Perouse stock shows that there was almost too much variability in both the width of the lamellae and the distance between them to make any valid generalization. But apparently there is some tendency for the lamellae parallel to (100) in the orthopyroxene to be closer spaced and narrower than the lamellae parallel to (001) in the clinopyroxene. This bears out the hypothesis mentioned above, but only to a limited degree.

The clinopyroxene in two rocks has been chemically analyzed by the rapid method. Table 4 shows the chemical analysis, the computed chemical formula, and the optical properties for the pyroxene.

Orthopyroxene is about as abundant in the layered rocks as clinopyroxene. It is present almost everywhere throughout the exposed succession, but is slightly more abundant in the lower part. In certain layers it is the dominant dark mineral. The composition of the orthopyroxene is about En 30 Fer 70. Like the clinopyroxene, the orthopyroxene occurs both as settled rounded crystals and as later interstitial crystals. In the latter form it is locally poikilitic. In a few places orthopyroxene contains patches of clinopyroxene that appear to have been derived from the orthopyroxene. Olivine is encased more often by orthopyroxene than by clinopyroxene.

Olivine is present locally throughout the layered stocks and like orthopyroxene appears to be more abundant in the lower part of the succession. Most of the olivine crystals are rounded, and for this and other reasons are believed to be settled crystals. The olivine, like the pyroxenes, is generally unaltered. The olivine contains some inclusions, but these are small and do not constitute as much as 1 percent of the mineral. Zoning has not been found in the olivine or in the pyroxene. Table 5 shows the composition and optical properties of olivine from one rock.

TABLE 4.—*Composition and optical properties of clinopyroxenes from the Astrolabe-De Langle stock*

[Analyses done by rapid method by Maxwell K. Carron, U.S. Geological Survey]

	Weight percent	Equivalent weight	Number of— Oxygen	Number of— Cations	Number of— Atoms
Clinopyroxene 52ARm d 40					
SiO_2	48.28	0.8039	1.6078	0.8039	Si=1.80
Al_2O_3	5.60	.0554	.1662	.1108	Al=.25
Fe_2O_3	2.32	.0145	.0435	.0290	Fe^{+3}=.065
TiO_2	1.29	.0161	.0322	.0161	Ti=.04
FeO	8.04	.1119	.1119	.1119	Fe^{+2}=.25
MgO	14.60	.3621	.3621	.3621	Mg=.81
MnO	.27	.0038	.0038	.0038	Mn=.01
CaO	18.96	.3381	.3381	.3381	Ca=.76
Na_2O	.70	.0113	.0113	.0113	Na=.05
K_2O	.02	.00002	.00002	.00004	K=----------
	100.08	-------------	2.67692	-------------	O=6.00

$$(\text{Ca Mg Fe})\ Si_2O_6\ \frac{6}{2.67692}=2.24138$$

Grouping of elements:
- Ca+Na+K=Ca
- Fe^{+2}+Mg+Mn=Mg
- Fe^{+3}+Al (excess)+Ti=Fe

Si+Al=2 (excess alumina added to Fe)

Formula: $Ca_{40}\ Mg_{43.4}\ Fe_{16.6}\ Si_2O_6$

Optical data:
- $n_x=1.6980\pm0.0005$ (average of 7 grains)
- $n_y=1.7215\pm.0005$ (average of 10 grains)
- $n_z-n_x=0.0235$

Dispersion (643 mμ−486 mμ) =0.015

TABLE 4.—*Composition and optical properties of clinopyroxenes from the Astrolabe-De Langle stock*—Continued

Clinopyroxene 52ARm g 36

SiO_2	48.92	0.8145	1.6290	0.8145	Si=1.82
Al_2O_3	4.84	.0479	.1437	.0958	Al=.21
Fe_2O_3	2.73	.0171	.0513	.0342	Fe^{+3}=.08
TiO_2	1.05	.0131	.0262	.0131	Ti=.03
FeO	7.06	.0983	.0983	.0983	Fe^{+2}=.22
MgO	14.12	.3502	.3502	.3502	Mg=.78
MnO	.52	.0073	.0073	.0073	Mn=.02
CaO	20.18	.3598	.3598	.3598	Ca=.81
Na_2O	.71	.0115	.0115	.0230	Na=.05
K_2O	.02	.00002	.00002	.00004	K=.02
			2.67732		O=6.00

(Ca Mg Fe)Si_2O_6 $\frac{6}{2.67732}$ = 2.2410

Grouping of elements as in 52ARm d 40.

Formula: $Ca_{42.4}$ $Mg_{43.4}$ $Fe_{14.3}$ Si_2O_6

Optical data:

n_x=1.6985±0.0005 (average of 9 grains)

n_z=1.7205± .0005 (average of 8 grains)

n_z-n_x=0.022

Dispersion (643 mμ−486 mμ)=0.0200 (based on determination of index on a single crystal in 4 immersion oils).
Index determined by immersion of grains in oil of known index, oriented on universal stage and match attained with variable monochrometer. Index of oil checked after use on refractometeter.

TABLE 5.—*Composition and optical properties of olivine, specimen 52ARm d 40, from the Astrolabe-De Langle stock*

	Weight percent	Equivalent weight	Number of—		
			Oxygen	Cations	Atoms
SiO_2	36.84	0.6134	1.2268	0.6134	Si=0.986
Al_2O_3	1.24	.0123	.0369	.0246	Al=.040
MgO	33.24	.8244	.8244	.8244	Mg=1.325
CaO	.32	.0057	.0057	.0057	Ca=.009
TiO_2	.08	.001	.002	.001	Ti=.003
Fe_2O_3					
FeO	27.83	.3874	.3874	.3874	Fe^{+2}=.622
MnO	.43	.0064	.0064	.0064	Mn=.010
Na_2O					
K_2O					
	99.98		2.48960		O=4.00

Sample analyzed by methods similar to those described in U.S. Geol. Survey Bull. 1036-C. Analyst: Maxwell K. Carron

(MgFe) SiO_4 $\frac{4}{2.48960}$ =1.60668

Grouping of elements:
- Si+Al=1 (Excess Al added to Fe)
- Mg+Ca+Ti=Mg
- $Fe^{+2}+Fe^{+3}+Mn$=Fe

Formula: $Mg_{67.1}$ $Fe_{32.9}$ SiO_4

Optical data:

N_z=1.738±0.002 (Average of 5 grains)

n_x=1.7005±.001 (Average of 11 grains)

n_z-n_x=0.0375

Dispersion (643 mμ−486 mμ)=0.015

PETROLOGY

It has been found by petrographic study that although the proportions of the minerals differ in different layers, the composition of the minerals varies only slightly throughout the entire section of layered rocks exposed in the Crillon-La Perouse stock. Figure 13 shows

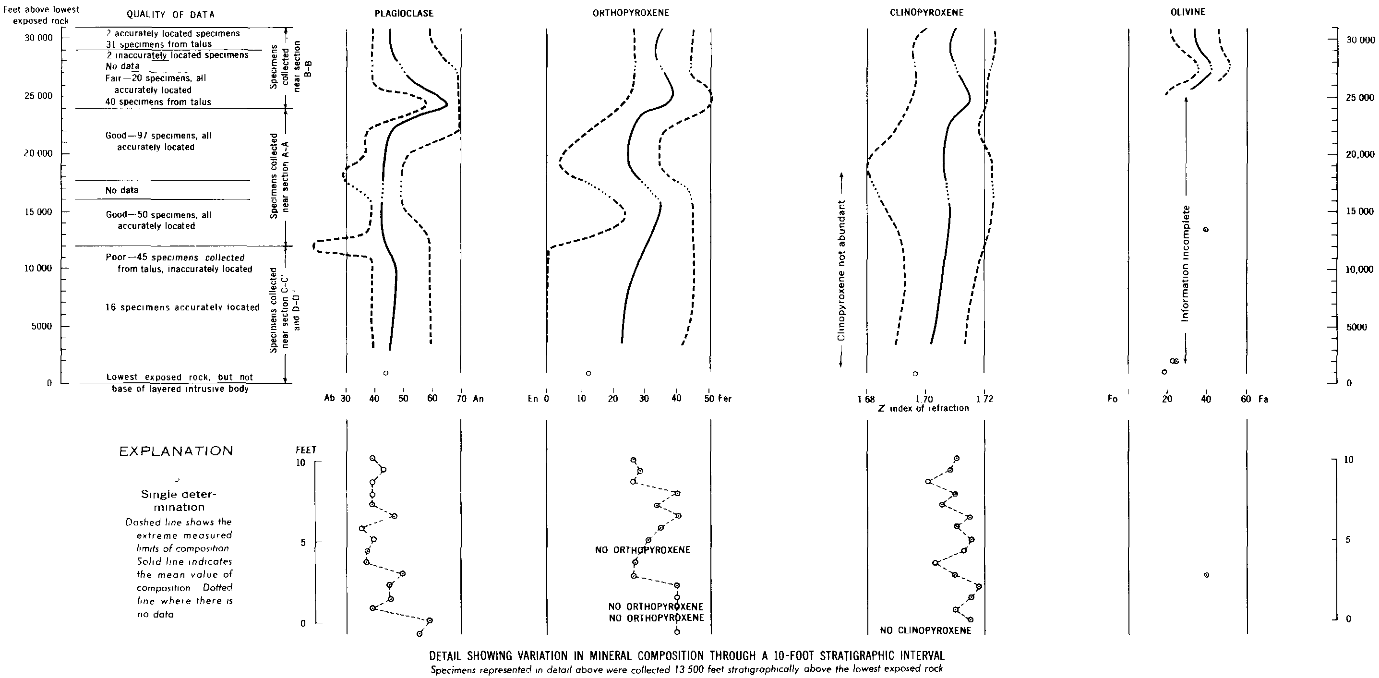


FIGURE 13.—Relation between mineral composition and vertical position in the Crillon-La Perouse stock.

the relation between the composition of the several mineral components and their vertical (stratigraphic) position in the Crillon-La Perouse stock. The outstanding feature of these relations is that although the stock contains a single continuous stratigraphic sequence more than 6 miles thick, the component minerals in it show little, if any, tendency towards differentiation. The curve showing the relation of the composition of the minerals to their vertical heights in the layered sequence indicates that the minerals become more calcic or more iron rich about 25,000 feet above the lowest exposed rock; this is the only trend that appears to be definite enough to be recognized with any degree of certainty. The curves show a general tendency for the plagioclase to become more calcic and the ferromagnesian minerals to become more iron rich upwards. These trends are so slight, however, that the writer doubts that any real trend is present; the range in composition from sample to sample may be several times larger than the trend indicated for the entire succession. It is believed that the sampling was adequate to detect any trend of normal magnitude. The Astrolabe-De Langle stock contains an exposed layered sequence about 2,000 feet thick, and like the Crillon-La Perouse stock, it shows no tendency toward differentiation.

Detailed petrographic work was done in a few areas on a few layers. One area on the south end of the Astrolabe Peninsula was studied in detail. The indices of refraction of the plagioclase in the layers were determined accurately by use of a universal stage and a quartz monochrometer. About 20 to 50 grains were measured for each point, and the value used was obtained by use of a frequency distribution technique. The results are believed to have high accuracy relative to each other and an absolute accuracy of approximately $\pm$ 0.001.

Ten layers making up a stratigraphic thickness of 18 feet were examined by this technique. In all, the index of the plagioclase was determined on 62 microsamples. The maximum change in anorthite content of the plagioclase based on index measurements is 8 percent, but the average range within a single layer generally is about 4 percent. No systematic relation could be found between the plagioclase composition and position either within a layer or from one layer to another. There appears to be some relation between the composition of the plagioclase and the grain size and bulk rock composition, for the plagioclase in the coarser grained and ferromagnesian richer rocks in many places is more sodic (fig. 14) than normal.

The plagioclase and clinopyroxene are believed to occur both as settled crystals and as later interstitial minerals. The earlier settled minerals in places have probably grown at the expense of the interstitial liquid, and the distinction between the settled crystals and the interstitial crystals is commonly difficult to see. The layers, as they are formed by crystal settling, obviously differed from one another in proportion of dark and light minerals. In some layers, therefore, the bulk composition (crystals plus interstitial liquid) differed from that of the magma. Thus, if a layer contained an unusually large amount of settled ferromagnesian minerals, a disproportionately large amount of clinopyroxene might crystallize, either because of a greater proportion of seed crystals or because of resolution with subsequent crystallization of clinopyroxene. If a disproportionately large amount of clinopyroxene crystallized, the remaining interstitial liquid might logically be expected to be somewhat impoverished in calcium so that the plagioclase crystallizing from this liquid would be more sodic. A study of the rock shown in figure 14 seems to indicate a consistent relation between the amount and grain size of the clinopyroxene and the composition of the plagioclase. The lowermost layer and central dark layer shown in figure 14 have an almost sympathetic relation between the composition of the plagioclase and grain size of the clinopyroxene—the coarser grain size, the more sodic the neighboring plagioclase. Much of the clinopyroxene is interstitial, and probably formed at the expense of the interstitial fluid by growing around original settled clinopyroxene grains. The upper layer shown in figure 14 is very nearly equigranular throughout, but the base contains sodium-rich plagioclase; here it is suspected that the crystallization of the clinopyroxene in the underlying layer (middle dark layer) in some way depleted of calcium the interstitial liquid in the overlying layer, giving rise to the more sodic plagioclase. The effect appears to extend about 0.8 of an inch into the upper layer.

Although the bulk composition of the rock differs markedly from one layer to the next, there appears to be no corresponding difference in the composition of the included minerals. Neither does there appear to be any correlation between the compositions of the different mineral species in any one rock; differences in composition of one mineral species are not reflected by corresponding differences in the composition of any other mineral species. These relationships were studied for all the rocks collected, numbering several hundred specimens, and it is believed that the data are sufficient to show these relationships definitely if they existed. In particular, the plagioclase definitely shows that its composition is not related to the composition of any other associated mineral, but possibly to the amount of other minerals (for example, clinopyroxene) as discussed in the last paragraph.

A crude measurement of the ratio of light to dark minerals in the layers was attempted from examination of colored photographs.

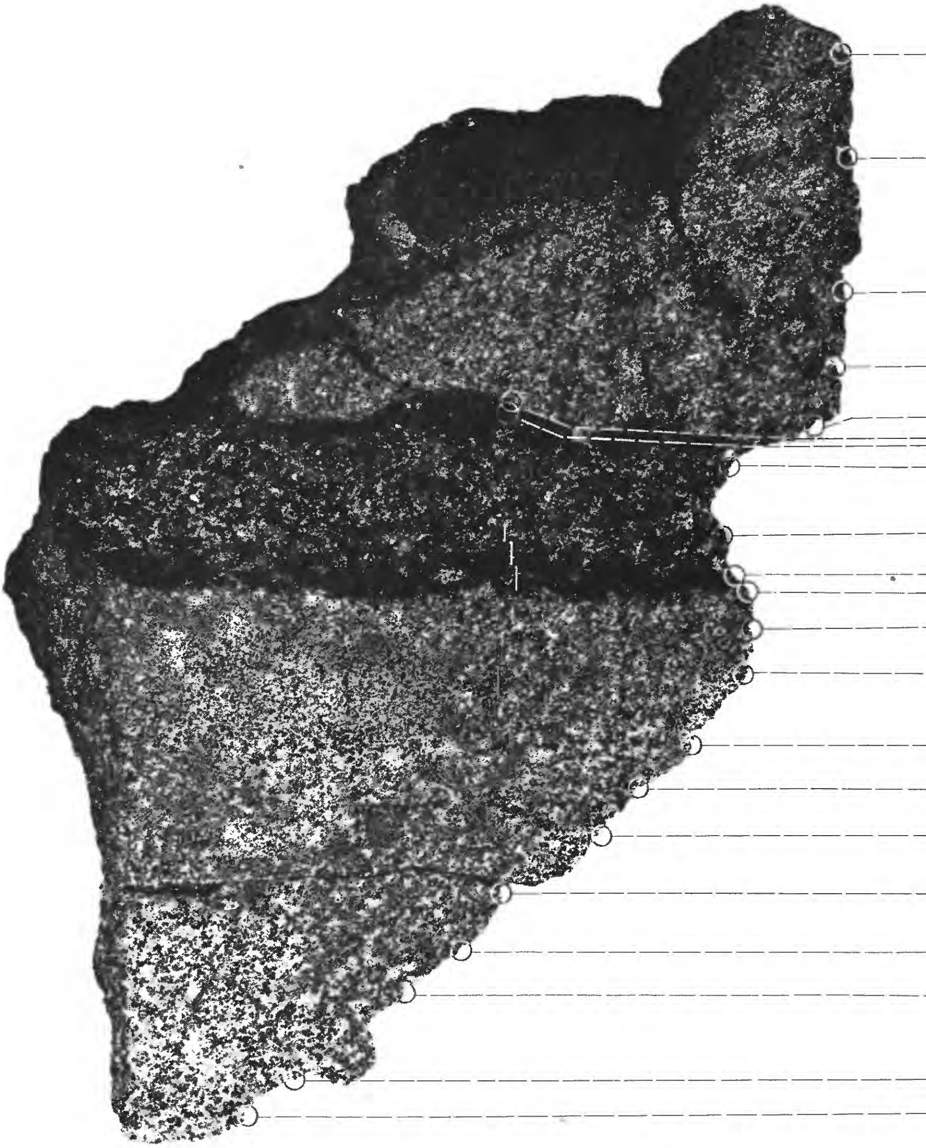
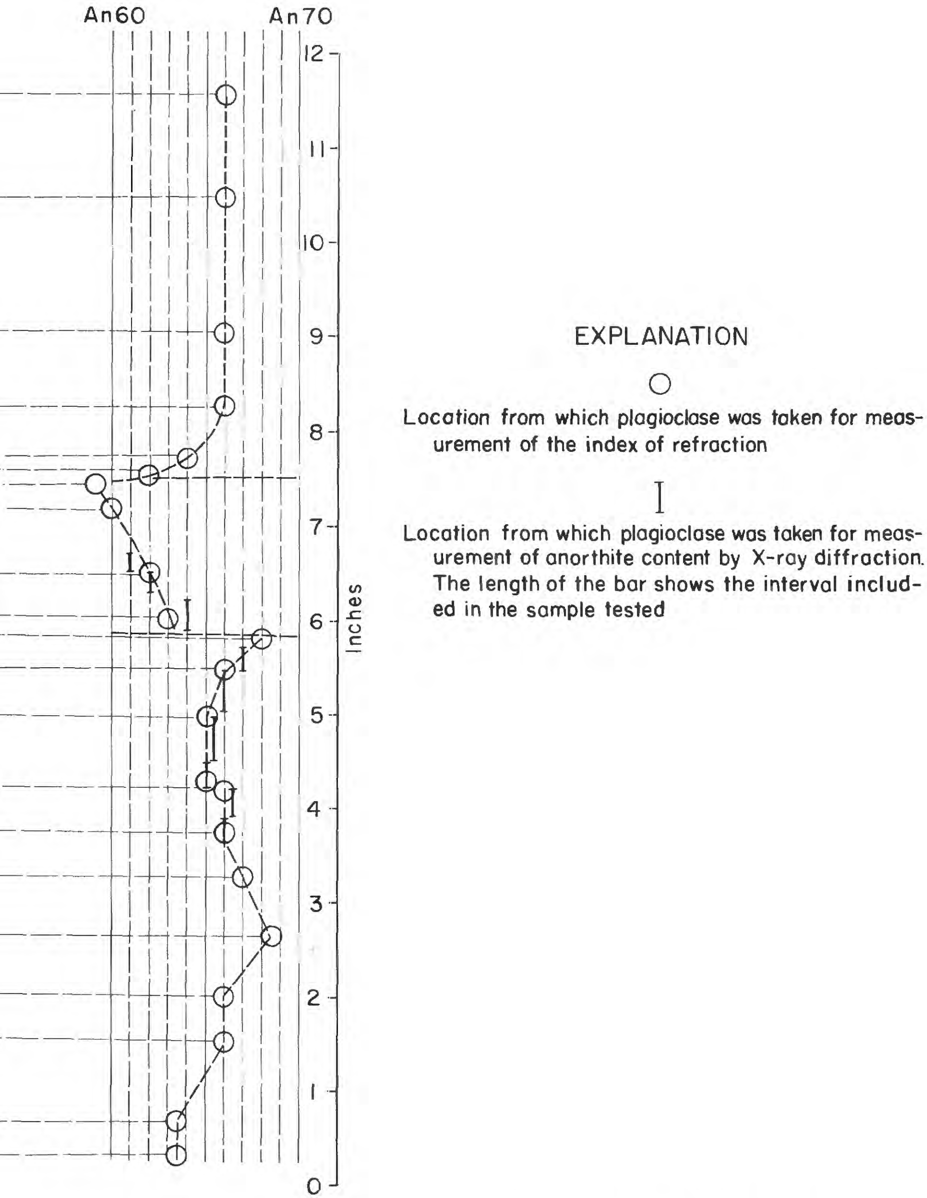


FIGURE 14.—Relation between plagioclase composition and layering. Note that the coarser grained rock contains the more sodic plagioclase, but that the coarse grains are clinopyroxene. Thin sections of the rock show that the plagioclase and clinopyroxene crystallized from interstitial liquid. It is believed that the continuous crystallization of the clinopyroxene in the layer from interstitial fluid brought about a slight relative calcium deficiency resulting in the crystallization of a more sodic plagioclase. Sample



from altitude of 10 feet, south end of Astrolabe Peninsula. The index of the plagioclase was determined by matching cleavage fragments in immersion oils using monochromatic light of variable wave length. n_x' was measured on 20 to 50 grains for each point, and n_x' was then determined from its frequency distribution. The results are believed to be accurate to $\pm$ 0.001.

When this ratio based on color intensity was plotted against the vertical position within the layers (fig. 15), it was found that not only does there appear to be a regular systematic variation upward through a layer, but also that the layers themselves differ systematically, one from the next, sometimes through as many as six layers. Possibly the regularly spaced light and dark zones, each composed of hundreds of layers, that are visible on the west cliff face of Mount Crillon are part of an even larger system.

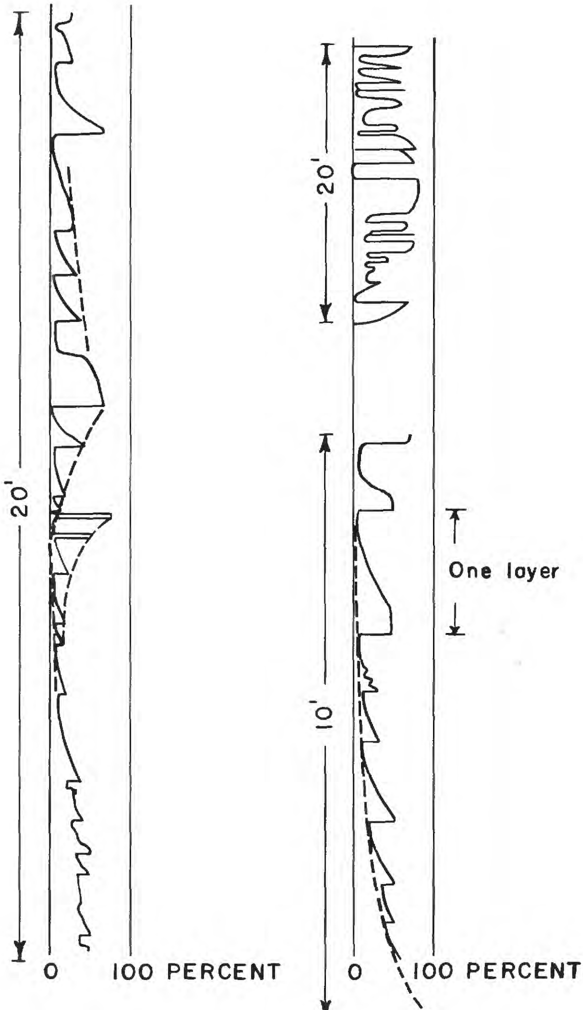


FIGURE 15.—Variation in percentage of dark minerals within layers and groups of layers in the Crillon-La Perouse stock. Dashed line indicates trend through several layers.

A few individual layers and several adjacent layers were studied to determine the ratio of light to dark minerals in a layer. On one specimen a count was made of the proportion of dark (pyroxene, olivine, and ilmenite) to light (plagioclase) minerals through three complete layers (fig. 16).

It is apparent from the diagram that each of the three layers varies in porportion of dark to light minerals in almost exactly the same way, although each layer is different in thickness. From this, the writer concludes that the same process or sequence of events took place for each layer formed. There is no systematic change in composition of the minerals throughout the three layers, and it appears most likely that the layers formed by physical rather than by chemical processes.

ORIGIN OF LAYERING AND DIFFERENTIATION

The layers are believed to have formed by crystals settling into stratiform sheets; each layer was, while forming, the floor of the magma chamber. The phenomenon of crystal settling through a moving liquid produced layers distinguished from one another by differences in grain size and in degrees of sorting, and in the amount of space occupied by interstitial liquid. The crystallization of the interstitial liquid has masked the original textures to some extent.

The layering ends in the contact zone instead of continuing parallel to the wallrock contact, as is believed to be the normal structural pattern of layered rocks in lopolithic or laccolithic bodies. Figure 3 shows an idealized diagram of the layered structures in the Crillon-La Perouse stock.

All the structural features that are related to the formation of the layers show evidence of current action and sedimentation processes similar to those in current-deposited sedimentary rocks, which indicate to the author that the layers were formed at the bottom of a liquid magma, as sedimentary layers are deposited from a body of water. There must have been at most times during the formation of the layers, a strong distinction in physical properties between a layer and the overlying magma. If the structures similar to ripple marks were formed by some form of oscillatory motion of the magma, then one might reasonably believe that periods in which layers were formed were followed by periods of quiescence. During such periods the surface of a layer gained some coherence before the next layer was laid down and remained in contact with the magma for relatively long intervals. In most layers, however, the deposition of one layer was followed quickly, if not immediately, by the next. Structural fea-

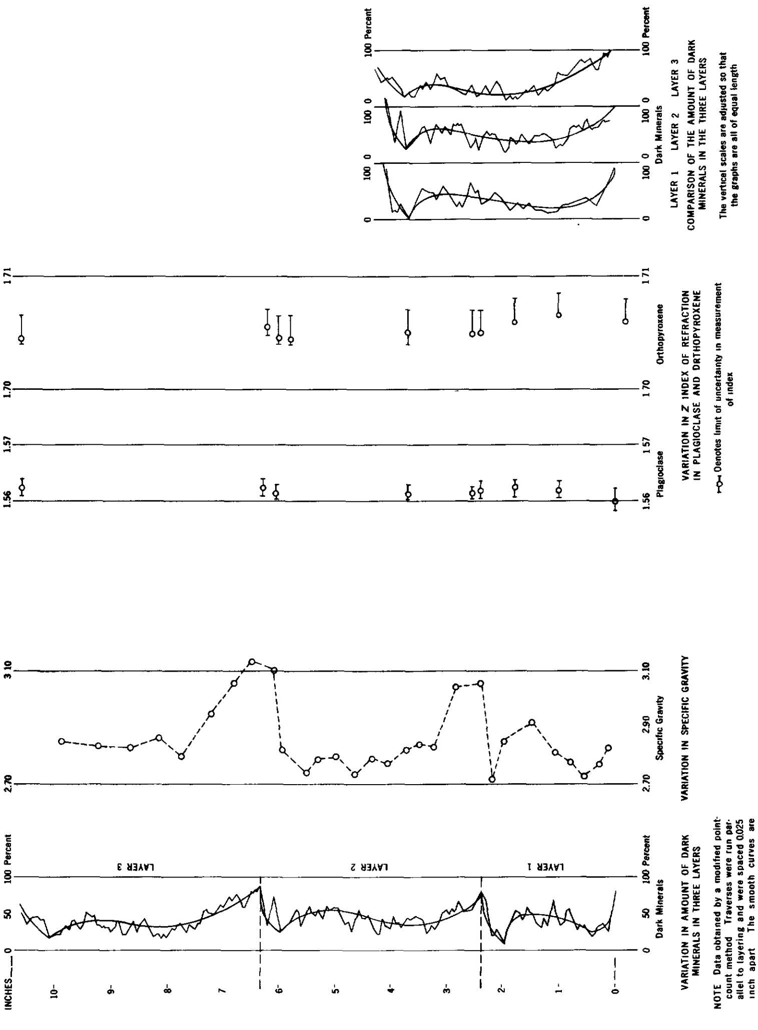


FIGURE 16.—Some physical relationships in three layers in the Crillon-La Perouse stock.

tures observed in the field indicate that slumping and sliding of partly solidified magmatic rock took place within the magma chamber particularly in areas near the contact.

On the other hand, there is little evidence indicating that the layers formed by some physical-chemical process. If the layers represent multiple injections, which on structural grounds alone is practically an untenable concept, one might expect that the differences in the bulk composition of the rock in a layer would be reflected in the composition of the minerals present in that rock. No such evidence has been found.

It is possible that layering in certain ultramafic rocks is caused by differential movement, apparently by some process of smearing out of rocks of contrasting composition into parallel layers. Evidence of such movement is lacking in the layered stocks in the mapped area, and it appears impossible to form such a structure as that in the Crillon-La Perouse stock by differential movement, no mater how complex the mechanism postulated. This seems obvious when one considers that the stock is exposed sufficiently well that the saucer-shaped structure can be clearly seen to extend without break from one end of the stock to the other and to remain virtually the same throughout a stratigraphic interval of more than 32,000 feet.

The bulk of the evidence indicates, therefore, that the layers were formed by currents which periodically swept across the floor of the magma chamber. The process is believed to be the same as that postulated for the deposition of graywackes by density currents on the ocean floor. Currents varying in velocity or in their vertical component of velocity, and containing crystals settling at different rates, would distribute the crystals differentially over the floor of the magma chamber. This would be true either for equal-size crystals of different specific gravities or for crystals with the same specific gravity but of different size. Thus, one could reasonably expect to find grading in grain size or size sorting even of monomineralic layers.

The fact that a layer may show some systematic grading in the light to heavy minerals up through the layer, and that groups of layers may also show a systematic trend upwards may be explained in the following manner: Intermittently some event (slides?) took place near the margins of the chamber that formed a cloud of crystals and rock fragments that swept out over the basin floor. Superimposed on the large forward movement were smaller eddies and swirls. The large current would deposit crystals in zones composed of layers which might in a general way show some systematic trend as the overall forward velocity changed. The smaller eddies and swirls, if regularly spaced and having the same form, would produce layers which were similar one to another. Accidents, such as the meeting of currents, would produce various kinds of layers in which no order was apparent. These probably are more common in the layered sequence than layers showing some systematic order.

The question as to why neither the Crillon-La Perouse nor the Astrolabe-De Langle stocks show evidence of differentiation cannot be answered by the writer. There is good structural field evidence indicating that the Crillon-La Perouse stock was not formed by multiple injection, and the same is probably true of the Astrolabe-De Langle stock. Possibly the magma came in as a solution and cooled, allowing crystals to form. If the magma was in enough motion (convection currents?), it would keep the minerals in suspension while they formed. The crystals would then constantly adjust to the liquid as crystallization proceeded. If this condition could be maintained until a large part of the magma had crystallized, it is conceivable that differentiation might be slight.

AGE

The schists in which the layered complexes are emplaced probably are broadly correlative with the rocks of Mesozoic age that crop out on Chichagof and Yakobi Islands (p. F10). A graywacke unit of probable Early Cretaceous age which crops out of Chichagof Island at Mirror Harbor is intruded by a layered gabbroic stock. Similar stocks also crop out on Yakobi Island. The type of igneous rock, the mode of intrusion, and the degree of metamorphism by the stocks on Chichagof and Yakobi Islands and those found in the area under discussion are similar, and it seems probable that the intrusions are all related and thus of approximately the same age. Therefore, it is believed that the layered rock bodies under discussion were intruded sometime during or after the Early Cretaceous epoch.

DIORITE AND QUARTZ DIORITE

Diorite and quartz diorite crop out in several small stocks northeast of Palma Bay, and diorite crops out near the head of Lituya Bay. Both rock types are widespread in southeastern Alaska, and where found on Chichagof Island are believed to be genetically related (Rossman, 1959a). The diorite appears to be in large part composed of older recrystallized rock, and the quartz diorite in general shows evidence of having been intruded into the position it now occupies.

Because neither the diorite nor the quartz diorite is extensively exposed in the area of this report, and because nothing unusual was noted concerning them, they are not discussed at length. Both rock types lie in the schist unit and thus are presumably younger, but no other age relations are known. A dike of dioritic composition cuts the layered gabbro on Mount De Langle, but its relation to the other diorite is not known. Two ages of quartz diorite have been recogniezd on Chichagof Island, one associated with, but younger than, the diorite; the other, believed to be still younger, cuts layered gabbro present there (Rossman, 1959a). A complete description and discussion of similar rocks are given in the report of Chichagof Island.

REGIONAL STRUCTURE

The regional strike of the Mesozoic(?) bedded rocks is northwest, about parallel to the axis of the Fairweather Range. In general, the rocks are more deformed in the northwestern part of the area than they are in the southeastern part. The Tertiary sedimentary rocks are also folded parallel to the regional trend. Near Icy Point they are overturned to the northeast, and farther northwest but south of Lituya Bay, they are folded into several northwestward-trending folds.

The structure indicates that schists originally present in the place now occupied by the layered gabbroic rocks must have been pushed upward and subsequently eroded.

The dioritic stocks found in the area do not appear to have displaced or structurally deformed the bedded rocks to any great extent. The texture and relation of the stocks to the bedded rocks indicate that the stocks were formed partly by the intrusion of a magma and partly by recrystalliaztion of the bedded rocks adjacent to the magma. This appears to be much the same type of process that has taken place on Chichagof Island and in the Dundas-Glacier Bay area (Rossman, 1959a, 1962).

Most of the large faults found in the mapped area trend northwestward parallel to the regional trend of the bedded rocks. A few faults, with a strong horizontal displacement, trend northeastward. One such fault system offsets the Astrolabe-De Langle stock (pl. 1). The displacement is such that the northwest side moved northeastward with respect to the southeast side. A large fault, the Fairweather, extends across the head of Lituya Bay and separates the slighly metamorphosed greenstone-slate sequence from the amphibole and biotite schist sequence. The Fairweather fault is part of the regional pattern of faulting that forms an arcuate network trending parallel to the coastal mountain ranges of Alaska. Most of these faults are high-angle thrust faults that dip toward the continent.

MINERAL DEPOSITS

METALLIC MINERALS IN THE LAYERED IGNEOUS ROCKS

The accessible exposures of both stocks were examined to determine whether they contained any large concentrations of metallic minerals. Where the rocks were found to contain concentrations of minerals of possible economic interest, hand specimens were taken that were estimated to be as representative as possible of the mineral zone. The location of all samples is shown on plate 1. The several mineral components were later separated by standard laboratory techniques and weighed. This study is the basis for the percentages cited below. Thus, both the sampling and method of analysis are inexact, but it is believed that the figures given indicate the general metallic mineral content of the rocks sampled.

The contact area of the Crillon-La Perouse stock, 1½ miles southeast of Mount Lookout, probably contains 10 to 25 percent ilmenite through a distance of several hundred feet from the contact, but the lateral extent along the contact could not be determined because of the extremely rough terrain. Figure 17 shows this area and indicates the probable outline of the ilmenite-bearing zone. Similar zones were noted on the south wall above South Crillon Glacier, but were not examined at close range. Samples from layers within a few hundred feet of the contact northwest of North Crillon Glacier contain 7 to 10 perecent ilmenite. Similar concentrations extend for several hundred feet away from the contact near the south ends of the Crillon-La Perouse stock but were not sampled. A few layers that contain some small concentrations of ilmenite as well as some sulfide minerals were found on both the north and south end of the Crillon-La Perouse stock well within the stock. Such layers are signaled in outcrop by bright rust-red outcrops, and it was from one of these that Kennedy took samples containing as much as 60 percent ilmenite (Kennedy and Walton, 1946).

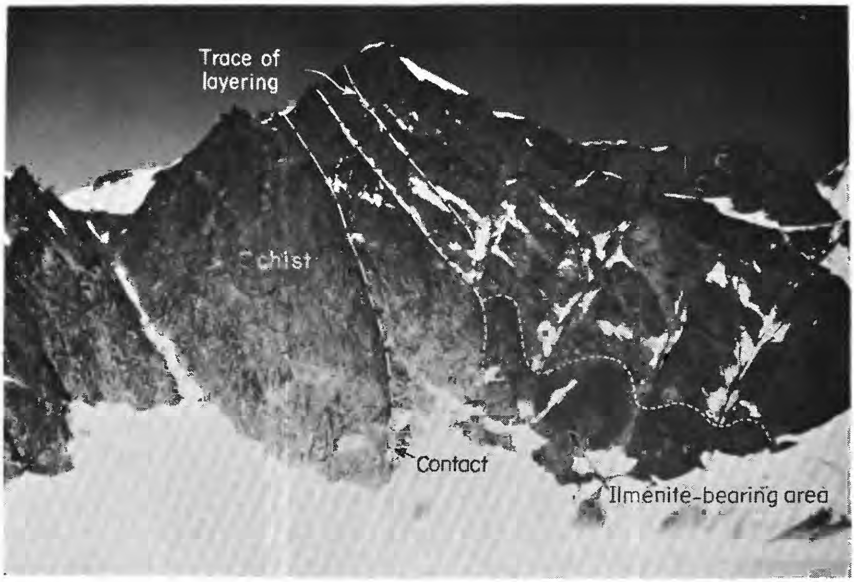


FIGURE 17.—Contact between layered gabbro and schist. Vertical relief is about 2,200 feet

As the highest concentrations of ilmenite in the Crillon-La Perouse stock were found near the contact, it is surmised that the ilmenite content of any layer may decrease toward the center of the stock; no such decrease was actually observed in outcrop, because individual layers could not be followed for more than a few hundred feet owing to the extremely rugged nature of the land.

Table 6 shows the amount of ilmenite present by weight in specimens collected from the Crillon-La Perouse stock.

TABLE 6.—*Ilmenite content of the Crillon-La Perouse layered stock*

Sample (Location on pl. 1)	Ilmenite (percent by weight)	Remarks
52ARm c 40	11. 4	Layer about 50 ft thick near contact; contains small amount of garnet. South end of Crillon-La Perouse stock.
52ARm e 40	7. 1	Same layer as c 40.
52ARm g 40	5. 0	Do.
52ARm a 43 b	Trace	Suite from 10 ft of layered rock near contact of Crillon-La Perouse stock.
52ARm a 43 h	2. 5	
52ARm a 43 m	. 2	
52ARm a 43 k	Trace	
52ARm s 47	. 2	South end of Crillon-La Perouse stock. About 21,000 ft above lowest exposed rock. Specimens collected several miles from contact.
52ARm a 48	. 2	
52ARm d 48	. 1	
52ASz b 41	7. 1	Near contact, north end of Crillon-La Perouse stock.
53ARm a 37	[1] 25. 0	Collected near the contact of Crillon-La Perouse stock. 3 miles northeast of Crillon Lake. Specimen contained 2 percent graphite by weight.

[1] Estimated.

Spectrographic analyses were made of concentrates of heavy minerals from nine samples. Table 7 shows the approximate total percent by weight of the elements in the concentrates.

The ilmenite commonly occurs as euhedral or subhedral grains less than 1 mm long. In polished sections the ilmenite appears uniform and shows no included magnetite or exsolution phenomena under the highest magnification. It does, however, contain several percent silicates in rounded inclusions. Ilmenite in beach sands that is believed to be derived from the Crillon-La Perouse stock has been partially analysed (Rossman, 1957), and these analyses show that the ilmenite contains between 47 and 52 percent TiO_2 with minor amounts of silica and magnesium. It is believed that the ilmenite from the Crillon-La Perouse stock is mineralogically satisfactory as a source of titanium for metallurgical purposes.

TABLE 7.—*Semiquantitative spectrographic analyses of concentrates of heavy minerals from specimens from the Crillon-La Perouse stock*

[Analyst: Janet D. Fletcher, U.S. Geological Survey]

Specimen	Cu	Pb	Ag	Sn	Mn	Co	Ni	Fe	Al	Ga	Cr
52ARm p 41	0.x	x.	0.00x	0	0.x	0.0x	0.x	x0.	0.x	0	0.00x
52ARm a 48	.x	.x	0	0	.x	.0x	.0x	x0.	.x	0	.x
52ARm s 47	.x	.x	0	0	.x	.0x	.x	x0.	.x	0	.0x
52ARm n 54	.x	.x	.000x	.0x	.x	.0x	.x	x0.+	.x	.00x	.x
52ARm g 40	.0x	.x	0	0	.x	.0x	.0x	x0.+	.x	0	.0x
52ARm e 44	.x	.x	0	.x	.x	.0x	.0x	x0.+	.x	0	.0x
52ARm a 60 i	.0x	.x	0	0	.x	.0x	.0x	x0.	.x	0	.0x
52ARm r 43	.x	0	0	0	.x	.0x	.x	x0.	.x	0	.0x
52ARm f 55	.0x	.x	.000x	0	.x	.0x	.0x	x0.	.x	0	.0x

Specimen	V	Sc	La	Ti	Zr	Ca	Sr	Ba	Mg	Na	Si
52ARm p 41	0.0x	0.00x	0.x	0.x	0	x.	0	0.00x	x0.	0.00x	x0.
52ARm a 48	.x	.00x	.00x	x0.	.0x	x.	0	.00x	x0.	.00x	x0.
52ARm s 47	.0x	.00x	.0x	.x	.00x	x0.	.00x	.0x	x0.	.00x	x0.
52ARm n 54	.x	.00x	.0x	x.	.000x	x.	0	.00x	x.	0	x.
52ARm g 40	.0x	.00x	.0x	x0.	.0x	x.	0	0	x.	0	x.
52ARm e 44	.00x	.00x	0	x.	.00x	x.	0	0	x.	0	x0.
52ARm a 60 i	.0x	.00x	.0x	x.	.00x	x0.	.00x	.00x	x0.	.x	x0.
52ARm r 43	.0x	.00x	0	.x	0	x.	.00x	.00x	x0.	.00x	x0.
52ARm f 55	.0x	.00x	.00x	x0.	.00x	.x	0	.00x	x.	.00x	x.

NOTE.—Looked for, but not found: Pt, Ir, Rh, Au, Bi, Mo, W, Ge, As, Sb, Zn, Cd, In, Y, Th, Nb Ta, U, Be, P, B.

	Percent
x0.0	10 to 100
x.0	1 to 10
.x	.1 to 1
.0x	.01 to .1
.00x	.001 to .01
.000x	.0001 to .001
0	Element not detected

The nickel deposit on Yakobi Island, in the basal part of a similar gabbroic body, was signaled by rust-stained surface outcrops; similar rust-staining was noted along the contact of the Crillon-La Perouse stock at several places. One of the most outstanding of these is exposed on the south side of the small glacier 3½ miles southeast of Mount Lookout. This contact could not be reached for close examination in 1952. Moreover, it is known that the contact between the layered rock and the enclosing amphibole schist on the north side of North Crillon Glacier is stained green from the weathering of copper-bearing minerals, but neither the extent of this staining nor the amount of the copper in the rock has been ascertained.

Some layers of the Astrolabe-De Langle stock contain concentrations of ilmenite, and other layers contain as much as 20 percent titanium-bearing magnetite. In places the contact also contains some titanium-bearing magnetite. Most of the layers that contain much magnetite or ilmenite crop out over a "stratigraphic" distance of about 1,000 feet near the top of the mountain making up Astrolabe Peninsula. The top of the mountain appears to consist of recrystallized older rock, and it is believed that the ilmenite and magnetite-bearing layers lie at the top or on the side of the stock. These layers lie between 1,100 and 2,000 feet in altitude and appear to extend through the mountain. Samples containing the highest concentrations of ilmenite and magnetite were picked up in talus on the west side of the mountain near its southwest end (samples $b_1$34 to $b_4$34. The large amount of such material indicates that the zone containing the ilmenite and magnetite is very extensive.

Table 8 shows the percentage of magnetite and ilmenite in samples taken from the Astrolabe-De Langle stock. The locations from which these samples were taken are shown on plate 1. The results were obtained by crushing rock samples, removing the metallic minerals by use of a heavy liquid (Clerici solution), and separating the magnetite from the ilmenite with a magnet. Two samples of magnetite from the Astrolabe-De Langle stock were analyzed and found to contain 10.69 and 8.85 percent TiO_2 by weight.

TABLE 8.—*Magnetite and ilmenite content, percent by weight, of rocks from the Astrolabe-De Langle stock*

[n.d., not determined]

Sample (Location on pl. 1)	Magnetite	Ilmenite
b_1 34	13. 5	n.d.
b_2 34	22. 0	n.d.
b_3 34	8. 0	2. 0
b_4 34	11. 0	2. 0
d 38	12. 0	4. 0
g 38	7. 5	7. 5
h 38	11. 0	3. 5
i 38	12. 5	4. 0
j 38	9. 5	2. 0
k 38	14. 0	4. 0
l 38	9. 5	2. 5
o 38	1. 5	3. 0
p 38	5. 0	n.d.
q 38	1. 0	2. 0
d 39	1. 0	4. 0
f 39	7. 0	n.d.
g 39	4. 5	12. 5

HEAVY MINERALS IN BEACH SANDS

The beach sands from Palma Bay northward to a point northwest of Cape Fairweather contain concentrations of heavy minerals. The heavy minerals include in decreasing order of abundance: garnet, pyroxene, ilmenite, magnetite, gold, and plantinum. A separate report on the beach sands has been prepared (Rossman, 1957), and only a summary is included here.

The greatest concentration of heavy minerals on the present beach is in the part that is no longer worked by waves. Most of this part of the beach is grass or brush covered, but it is generally exposed on the oceanside of the beach which is eroded by wave action during the more severe winter storms. The heavy-mineral bearing zone is in places as much as 200 or 300 feet wide, and it may extend for several miles along the beach.

The beaches that contain the largest known concentration of heavy minerals lie in the area between 2 and 13 miles south of Lituya Bay, but other concentrations are found along the beach north of Lituya Bay.

Because the heavy minerals have been concentrated by wave action, their distribution throughout the beach is not uniform. They tend to be concentrated near the surface in the landward part of the beach where they are undisturbed by waves except those of the severest storms. Cuts through the beach deposits showed that the concentration of heavy minerals may extend to a depth of at least 20 feet. Possibly other concentrations are present below this depth, but the greatest concentrations appear to be in the upper part of the beach deposits.

There are several wave-cut terraces above the present beach, and those below 200 feet in altitude are known to be partly covered by sands containing concentrations of heavy minerals. Prospectors found that some of the older beach sands contained a higher concentration of gold than some of the more modern ones.

The concentration of ilmenite and gold in the beach sands in the area between Palma Bay and Cape Fairweather is possibly high enough to make mining worth while. At present little can be said regarding the tenor or the volume of these deposits. They probably do not contain as much as 5 percent ilmenite except in small areas.

SUMMARY OF THE POSSIBILITIES OF ORE DEPOSITS WITHIN THE MAPPED AREA

Gabbroic rock, in general, is believed to be a favorable environment for the formation of deposits of ilmenite and magnetite, and the contact area between gabbro and enclosing rock is a favorable geologic environment for copper and nickel mineralization. Both the Crillon-La Perouse and the Astrolabe-De Langle stocks have been examined sufficiently well so that any large continuous layers of high concentrations of ilmenite or other metallic minerals of economic importance would probably have been discovered. The contact area could not be examined except at a few places because of its almost universal inaccessibility, but the fact that some mineralization was noted at almost every point where it was examined leads one to believe that small ore bodies may be present along the contact. At many places the contact, although inaccessible, could be seen to be heavily covered with a bright rust-red stain. A closer examination of the contact is warranted.

The fact that platinum was found in the present beach sands indicates that platinum is probably present at some place within the layered complex. In other parts of the world, such as in the Stillwater complex in Montana, the platinum has been associated with sulfide-rich zones, and anyone prospecting in this area should not overlook the possibility that sulfide-bearing rock may contain some platinum.

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