The Eastern Front of the Bitterroot Range Montana

By CLYDE P. ROSS

CONTRIBUTIONS TO GENERAL GEOLOGY, 1950

GEOLOGICAL SURVEY BULLETIN 974-E

A discussion of the origin of the gneissic rocks on the eastern border of the Idaho batholith

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1952

The Eastern Front of the Bitterroot Range Montana

GEOLOGICAL SURVEY BULLETIN 974-E

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY
W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. — Price $1.00

CONTENTS

ILLUSTRATIONS

THE EASTERN FRONT OF THE BITTERROOT RANGE MONTANA

By Clyde P. Ross

ABSTRACT

The origin of the gneissic rocks on the eastern border of the Idaho batholith in the Bitterroot Range, near Hamilton, Mont., has long been in dispute. Lindgren regarded these rocks as the product of stresses related to a normal fault along the front of the range with an eastward dip of about 15°. He thought both the hanging wall and the footwall had moved, with a total displacement along the fault plane of at least 20,000 feet. The faulting was believed to have been so recent as to be a major factor in the present topography. Langton appears to accept the concept of faulting but to regard the gneissic rocks as formed much earlier from a granitic rock that was more silicic and older than the Idaho batholith.

Reexamination of the evidence in field and laboratory leads to the conclusion that the gneiss bordering the batholith in the Hamilton quadrangle more nearly resembles a sedimentary than an igneous rock, both in general aspect and in details of texture and composition. It is a stratified rock that has been recrystallized but has retained even the minor features of its original lamination. Feldspars and other minerals have been developed in it, probably as a result of permeation by emanations from the batholith during intrusion. The rocks from which the present gneissic mass developed differed among themselves in their details of composition. They are thought to have been components of the Ravalli group of the Belt series, with their characteristics now obscured by partial granitization. So many features of sedimentary rocks are present that the concept of the gneiss's derivation from an old granite is not regarded as acceptable.

INTRODUCTION

PREVIOUS WORK IN THE AREA

The origin of the impressively straight part of the Bitterroot Range on the western border of the long valley in which Hamilton, Mont., is the principal settlement has been a matter of debate among geologists since Lindgren's reconnaissance in 1899. He was impressed by the straightness of the mountain front, and in his report (1904) he called attention to the smooth slopes, which he estimated to be inclined at angles of 15°-26°. He interpreted these smooth inclined slopes to mean that the rocks composing this part of the Bitterroot Range comprise a sheet of pressed and deformed granite that resulted from normal faulting of low dip, involving both stretching and shearing of the rocks.

Throughout his report, Lindgren used the term "granite" in the broad sense, not implying that the rock has precisely the composition of a true granite. Similarly, in the present report, the adjective "granitic" refers to rocks of igneous character with compositions corresponding broadly to that of granite. The precise composition may range from that of a true granite to quartz monzonite, with minor quantities of even more calcic rocks. "Granitoid," however, is used solely with reference to texture.

Lindgren stated that the gneiss bore "evidence both of molecular and molar movements." In other words, there was molecular rearrangement of the constituents into new and differently oriented mineral grains and, also, rearrangement of rock masses as a result of fracture on a large scale.

Such a fault as that postulated by Lindgren would be an exceptional one and should have left readily recognizable evidence of its presence. Whatever direct evidence of fracture or crushing is observable in the gneiss either took place before recrystallization or is so trivial that it does not fit the postulate. Likewise, the geomorphologic conditions do not fit. The spur ends at the eastern border of the range have triangular facets that might be supposed to be fault scarps or fault-line scarps, but examination shows that they are dip slopes and that the topographic forms are best explained as resulting from differential erosion. Abnormalities in stream gradients are such a widespread feature in this region that their presence here is not significant. True, the region has had a complex, imperfectly understood structural history, and the Bitterroot Valley may contain buried faults, but even so, the present writer has concluded that the straight, faceted front of the Bitterroot Range—so conspicuous as to have aroused the interest of Lindgren, Langton, and all the other geologists who have seen it—is not genetically related to normal faulting. This conclusion holds whether or not faults are concealed beneath the alluvium of Bitterroot Valley.

Lindgren's report (1904) is one of a group in which he laid the foundations for all subsequent work in Idaho and on its borders. Most of the conclusions he presented have proved to be essentially correct, but a few of his hypotheses require fundamental modification in the light of modern concepts. The hypothesis as to the origin of the front of the Bitterroot Range is one of these. The interpretation here offered is that the banded rock of the range front is granitized sedimentary rock, constituting a part of the widespread but variable and discontinuous gneissic border of the Idaho batholith, and is not a result of pressure during faulting. Such pressure may, however, have been a factor in producing the valley east of the range.

The only published report dealing in detail with the origin of the front of the Bitterroot Range and based on studies later than Lindgren's is that of Langton (1935). He accepts the concept of crushing advanced by Lindgren but apparently regards the postulated fault as an eastward-dipping thrust. Such a postulate does not agree with the probable regional structure. Langton appreciated the fact that the rock Lindgren regarded as pressed and deformed granite differs significantly in composition from the normal rock of the Idaho batholith. He offered the theory that this rock was a granitic mass, older and more silicic than the batholith, that became gneissic through deformation subsequent to its intrusion. This concept, like that of the thrust fault, is not in harmony with available data on the regional geology and receives little support from the facts Langton presents.

In Pardee's recent summary of block faulting in western Montana (1950, pp. 389-390), he continues to accept Lindgren's concept of a major fault at the base of the Bitterroot Range but regards favorably the present writer's hypothesis (Ross, 1947b, c) that the gneissic structure in the rocks of the range front is related to the intrusion of the Idaho batholith and hence is much older than the postulated fault.

The correct interpretation of the complex structure in this part of Montana, especially in areas north and east of the Hamilton quadrangle, is of great importance. In particular, it is related to the mode of emplacement and the age of the Idaho batholith. Detailed studies over a much larger area than the Hamilton quadrangle would be needed in order to add materially to the data already on record. The present report is a contribution toward the comprehension of the regional structure but is confined to the discussion of features that bear directly on the origin of the gneiss on the eastern slopes of the Bitterroot Range.

SCOPE OF THE PRESENT INVESTIGATION

The present paper is a byproduct of field work done in western Montana in connection with the compilation of a new geologic map of the State, now in preparation. About a month in 1946 was devoted to study and reconnaissance mapping in the Hamilton quadrangle, mostly along the eastern side of the Bitterroot Range. This area was revisited and additional traverses were run in areas to the north and south of it in 1947 and 1948. Through previous studies in Idaho the author had become familiar with areas to the west and south of that here discussed, especially in the region south of latitude 46° N. As the area under consideration is on the eastern border of the Idaho batholith, data on that great igneous mass and on its environs are important to its interpretation.

According to the broad definition adopted by the U. S. Geographic

Board (now the Board on Geographic Names) in its Sixth Report, the crest of the Bitterroot Range forms much of the western border of Montana, but according to Lindgren's definition (1904, p. 13), which seems preferable, it extends only from Lolo Pass to Nez Perce Pass along the boundary between Montana and Idaho. The present discussion is concerned primarily with that part of the eastern front of the Bitterroot Range that lies in the Hamilton quadrangle (fig. 43).

The geologic map of the quadrangle (pl. 4) is based on the author's field work, supplemented by data taken from a map included in Langton's report (1935) which covered an area extending into the northern part of the quadrangle as shown on figure 43. Because of the availability of Langton's data, which were suitable for use in compiling the new State map, the parts of the Hamilton quadrangle that had been mapped by him received less attention in the field than the essentially unmapped parts of the quadrangle farther south.

REGIONAL GEOLOGIC SETTING

The area under discussion is along the northern part of the eastern border of the Idaho batholith (Ross, 1936), a relatively flat-topped, steep-sided granitic mass that occupies most of central Idaho. The batholith is composed mainly of faintly gneissic quartz monzonite and allied material and has a thin, discontinuous border zone of diverse rocks in many of which gneissic texture is conspicuous. Much of the border zone that is not highly gneissic is more calcic in composition and was emplaced somewhat earlier than the main body, although these calcic rocks are not represented in the Hamilton quadrangle. The batholith is flanked on both sides and locally intruded by smaller bodies of granitic rock. In Montana such stocklike masses are numerous and extend from the immediate vicinity of the Idaho batholith on the west to the Boulder batholith on the east.

It appears that to a considerable degree the Idaho batholith made way for itself by pressures actively exerted during intrusion, rather than by passively occupying a space already provided for it (Ross, 1936; 1937, pp. 80-82; 1947a, pp. 1125-1127). Although the extent to which this concept is to be accepted may be open to debate, the presence of zones of locally intense folding, crumpling, and fractures in the sedimentary rocks near the batholithic contacts is abundantly attested by field observation in numerous localities, especially along the southeastern part of the batholithic border. These features, in several areas, have been shown to be independent of the regional structure.

The greater part of the main body of the batholith is believed to have consolidated essentially as a unit or an aggregate of large units

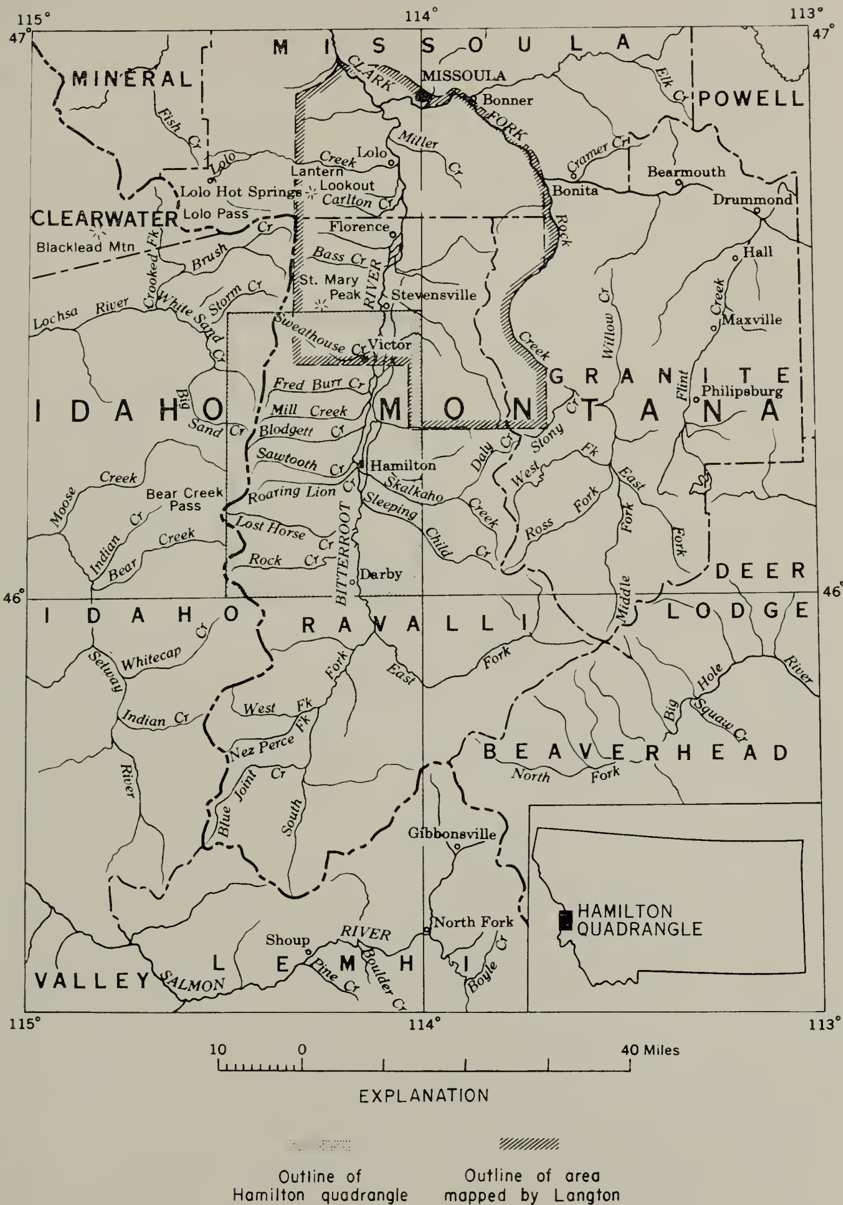

FIGURE 43.—Index map showing the Hamilton quadrangle, Mont., and its environs, including the boundaries of the area geologically mapped by C.M. Langton, Lolo Pass, and other features mentioned in the text that are beyond the limits of the quadrangle. The insert shows the relation of the quadrangle to the State of Montana.

in strong contrast to the assemblage of numerous discrete bodies that make up such a pluton as that of the Sierra Nevada in California (Calkins, 1930, pp. 120-129; Cloos, 1932, 1933, 1935). Some subdivisions of the Idaho batholith are known and others are expected to be discovered as detailed mapping progresses, but it is improbable that these future discoveries will change the broad picture of the batholith.

Both the central mass and those parts of the border zone that have a granitoid rather than a definitely gneissic or laminated structure are believed to have been formed by consolidation from magma, although both have probably been modified by changes subsequent to consolidation of the greater part of the magmatic material. Anderson (1942) has summarized data on the petrographic features of the batholith and those parts of its border zone that are of magmatic origin and now have compositions only moderately more calcic than the main mass. He specifically excludes from his discussion those parts of the border zone that are "granitized" or that are of exceptionally calcic composition, and he points out that in general the late-stage changes have tended to increase the proportions of silica, potash, and minor amounts of other constituents. The present paper deals with a particular part of the border zone in which, for reasons to be summarized, granitization is thought to have taken place to a moderate extent.

The date of emplacement of the Idaho batholith can be fixed in general terms only, because the rocks of known ages in contact with it are either far older or far younger than the batholith, as might be expected on the borders of so large an igneous body. On the basis of inferences, most of which are outlined in the reports cited, the writer believes that the batholith is not younger than middle Cretaceous nor older than Late Jurassic. The Boulder batholith, which is east of the area shown in figure 43, has been assigned an early Eocene age (Billingsley, 1916; Grout and Balk, 1934, p. 878) on evidence slightly more direct than that available for the Idaho batholith. The smaller granitic bodies intermediate in position between these two major intrusive masses are thought by the writer to be intermediate in age as well. This last inference, although a logical one, is supported so far by little direct evidence and bears on the present discussion only to the extent of implying that the various separate masses of granitic rock in and near the Hamilton quadrangle need not be intimately related genetically to the rock of the eastern front of the Bitterroot Range.

EARLY CONCEPTS OF THE AREA

In early studies (Becker, 1885; Eldridge, 1895, pp. 224-225; Bell, 1902?), the Idaho batholith and the marginal facies were regarded, with some reservations, as belonging to the complex assemblage of rocks then considered to be of "Archean" age. One of Lindgren's basic contributions (1899, p. 79; 1904, pp. 17-23) to the geology of the region was the recognition that the granitic rock is intrusive and, for the most part, surely of post-Paleozoic age. He regarded it as probably of post-Triassic age, and later work has not produced incontrovertible evidence for more precise dating.

Lindgren's conclusions were based on field work during the period 1896-99. At that time he believed that the gneissoid rocks were "of very differing ages." Some he considered to be "later than the granite, of which they, indeed, are only a modification, caused by peculiarly applied stresses." These gneisses, like the granite, he thought of as post-Triassic in age. However, he regarded other gneisses in the region as older than the sedimentary rocks intruded by the granitic rock and probably of pre-Cambrian age. He placed the gneissic rock along the eastern border of the Bitterroot Range in the group of post-Triassic rocks and said it was "clearly nothing but a sheet of pressed and deformed granite." He included in the gneiss of supposed pre-Cambrian age that of the xenolith or pendant on St. Mary Peak (fig. 43), part of which extends southward into the northwestern part of the Hamilton quadrangle, the gneiss of a large area that extends from the head of the Bitterroot River across the divide into the vicinity of Shoup, Idaho, and also gneiss in other areas farther west. Material of magmatic derivation in all these areas of gneissoid rocks is now generally regarded as allied in age and genesis to the Idaho batholith, although the relations to preexisting rocks and to the batholith are far from uniform and require more study before they can be completely understood.

Langton (1935, pp. 41-42) gives details regarding the gneiss of St. Mary Peak that indicate that the rock is not "Archean" as Lindgren supposed. As to the main body of gneiss on the border of the batholith, Langton's concept is that it is derived from granite more silicic and older than the quartz monzonite of the batholith. In the area near Shoup, Idaho (T. 19 E., R. 24 N.), Umpleby (1913, pp. 41-42, 48, pl. 6), like Lindgren, came to the conclusion that the gneiss is very old, but more detailed work by Davidson (1939) and his co-worker Gray has proved that the gneiss is intrusive into rocks of the Belt series and probably closely allied to the Idaho batholith. The present writer visited Davidson and Gray in the field and in addition has seen evidence that agrees with theirs in other parts of Idaho. It appears that there is no gneiss anywhere in or near central Idaho that corresponds in age or genesis to the gneiss considered "Archean" by earlier writers on that region. Gneiss of this general character may be present in southwestern Montana and adjacent parts of Idaho, although, even there, the antiquity of certain masses previously so assigned is being brought into question in recent work, part of which has been reported on by Klepper (manuscript in preparation).

GEOLOGIC EVIDENCE IN AND NEAR THE HAMILTON QUADRANGLE

The geologic map of the Hamilton quadrangle (pl. 4) shows 12 geologic map units. Of these, the alluvium, glacial deposits, Tertiary sediments, and volcanic rocks have little bearing on the problem under discussion. For present purposes, therefore, the map explanation gives sufficient information as to the character of these units. The only pre-Tertiary sedimentary rocks shown belong to the Belt series. These are regarded as belonging to the Grinnell argillite and to the Wallace formation or its equivalent the Newland, which is in agreement with the correlations shown on Langton's map. Other components of the Belt series are exposed farther north, as will be noted.

Six map units consist of rocks that are at least partly composed of material derived from granitic magma in one way or another. They include (1) the definitely granitic rock of the main part of the batholith; (2) smaller bodies of broadly similar but, on the whole, more potassic rock in outlying masses mostly east of the Bitterroot Valley; (3) distinctly gneissic granitic rock associated with and gradational into the granitic rock east of the valley; (4) injection gneiss, which includes rocks that in large part have the appearance of metamorphosed sedimentary rock but have been subjected to lit-par-lit injection; (5) xenoliths and detached pendants in the Idaho batholith, in part composed of injection gneiss; and (6) the stratiform gneiss of the border zone of the batholith, which is the rock unit of primary concern in this report. In general, wherever any one of these six units is in contact with any of the others of this group, the contact is gradational, whereas all other geologic contacts in the area are relatively sharp. According to the hypothesis advocated in the present report, the last three of the units just listed consist mainly of sedimentary rocks that have been modified as a result of intrusion.

Those features of the different map units that are significant with respect to the origin of the border-zone gneiss are outlined in the following sections. In accordance with the reconnaissance character of the field work, exhaustive petrographic studies of the material collected have not been undertaken. However, material representative of most of the different kinds of rocks mentioned has been examined in thin section, and data of significance are incorporated in the descriptions that follow. Both Lindgren and Langton have furnished petrographic information, which is taken into account in the descriptions. In general, the composition of the rocks is simple, and the effects of alteration by near-surface processes are surprisingly slight. In thin section, the rocks have a much fresher appearance than comparable rocks from areas in Idaho familiar to the writer.

SEDIMENTARY ROCKS

Only small, isolated patches of relatively unmetamorphosed pre-Tertiary sedimentary rock crop out within the Hamilton quadrangle. In order to give an adequate picture it seems desirable to include here a summary of data on such rocks in neighboring areas. Much of this information is not otherwise available.

No Paleozoic or Mesozoic sedimentary rocks are recognizable to the south, west, or north of the Hamilton quadrangle, except for small patches of limestone of supposed Cambrian age west of Missoula. With this exception, the nearest such rocks are about 30 miles east of Hamilton (Calkins and Emmons, 1915). This statement is based largely on the writer's reconnaissance work in connection with compiling the State geologic map of Montana and, previously, that of Idaho (Ross and Forrester, 1947). It is supported by Langton's description of an area that stretches 25 miles north of the Hamilton quadrangle (fig. 43). Thus the present distribution of the rocks strongly favors the idea that in this region the only sedimentary rocks involved in the intrusion of the Idaho batholith belonged to the Belt series. Identification of the different units of the Belt series that are present cannot be so positively made, in part because the nomenclature of these units is not satisfactorily standardized. In the present report the nomenclature outlined in a talk before the Geological Society of Washington in 1947 (Ross, 1949) is followed. For the Hamilton quadrangle and areas immediately northwest, north, and east of it, this nomenclature is shown in the accompanying chart.

Within the Hamilton quadrangle the rocks recognizable as components of the Belt series are in isolated patches whose mutual stratigraphic relations are not observable. The quartzitic argillite in the northeastern part of the quadrangle has enough of the lithologic characteristics of the Grinnell argillite to justify its assignment by Langton to that formation. The other unit of the Belt series named on plate 4, exposed at intervals along the eastern border of the quadrangle and in a few areas in the western part, is distinctly calcareous and locally has structures visible on weathered surfaces that are regarded as characteristic of the principal calcareous formation of the Belt series, so that the correlation can be made with confidence for most exposures. In this part of Montana the formation is sometimes called the Newland, sometimes the Wallace. The latter name seems

Stratigraphic subdivisions of the Belt series near the Hamilton quadrangle, Mont.

Group	Formation	General character
Missoula	Garnet Range, McNamara, Hellgate, Miller Peak (possibly others)	Dominantly red and green, locally gray argillite and argillaceous quartzite, with subordinate impure limestone
Piegan	Wallace or its equivalent the Newland (possibly others)	Impure siliceous limestone, calcareous argillite, and quartzitic argillite
Ravalli	Grinnell	Bluish-gray to reddish-purple argillite and argillaceous quartzite
	Appekunny	Gray argillitic quartzite
	Prichard	Brown to gray argillaceous quartzite or quartzitic argillite, mostly much metamorphosed

preferable, because the rocks are probably essentially coextensive with those of the type locality of the Wallace formation. As the stratigraphic position of the unit seems well established on the basis of lithologic character and of stratigraphic relations in neighboring areas, the name chosen is relatively unimportant. None of the rocks referred to in this paragraph have been studied under the microscope.

Langton mapped a small area immediately north of Big Creek as belonging to the Newland or Wallace formation. Similar rocks extend south across the stream to the vicinity of the Curlew mine. Lindgren (1904, pp. 49, 86-87) speaks of these rocks as quartzite and limestone, shattered and cut by fracture planes. He says that in places the quartzite grades into "typical contact metamorphic hornfels."

In a broad area north of the Hamilton quadrangle Langton (1935) mapped a complex assemblage of fault blocks composed of rocks that he assigned to the Prichard, Appekunny, Grinnell, Newland, Spokane, and Helena formations and, in addition, numerous rocks belonging to subdivisions of the Missoula group. All are components of the Belt series of pre-Cambrian age. Only the Prichard and Appekunny formations are mapped by Langton as in contact with the Idaho batholith. The Appekunny is distinguished from the Prichard because it is the more quartzitic and consequently the more massive of the two. From remarks in Langton's paper and from observations by the writer, it is clear that near contacts with the Idaho batholith the rocks of both these formations have been in various degrees fractured, crumpled, metamorphosed, and invaded by igneous material. Some of the outcrops in areas which Langton mapped as containing beds of the Appekunny or Prichard formations are fully as gneissic as parts of his "older gneiss" or the "border-zone gneiss" described in this report and are similarly placed with respect to the batholith. For example, figure 44 shows rock which Langton mapped as belonging to the Appekunny formation, but which contains light-colored aplitic laminae and is quite as gneissic as the darker parts of the border-zone gneiss. Several miles north of Sweeney Creek, however, rock belonging to this same body, as mapped by Langton, is less metamorphosed, and on the basis of lithologic character its assignment to the Appekunny formation is reasonable.

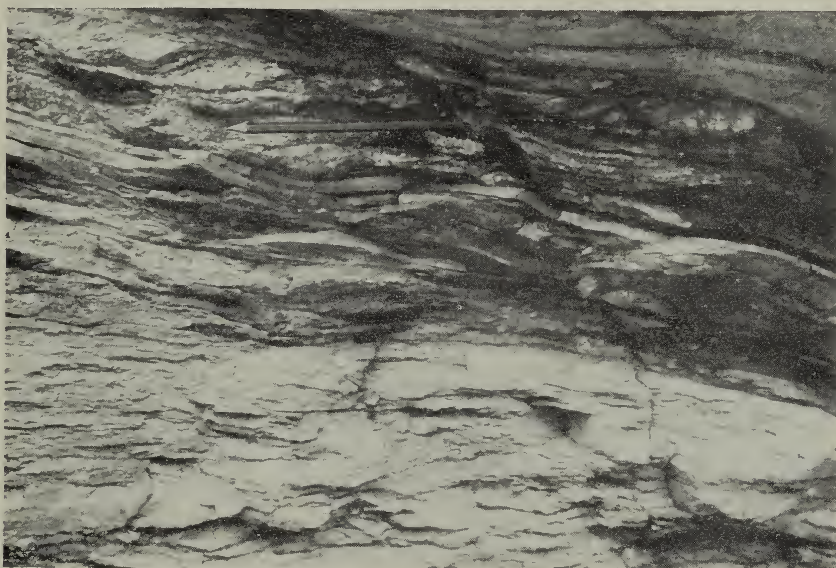

FIGURE 44.—Beds of the Appekunny(?) formation at the mouth of the canyon of Sweeney Creek, north of the Hamilton quadrangle, Mont. Note the granitoid structure and the thin aplitic sills along some parting planes.

Likewise, much of the rock Langton assigned to the Prichard formation is almost as thoroughly metamorphosed as the border-zone gneiss described in the present report. It is a much-crenulated rock with closely spaced biotite-coated parting planes parallel to the laminae (fig. 45) and thus is readily distinguished from most other parts of the Belt series, which are more massive. The metamorphosed rock assigned to the Prichard is thoroughly recrystallized and consists largely of quartz and biotite with subordinate plagioclase (probably mostly andesine). Some of it contains small stringers and irregular bodies of aplite, which in part cut across the bedding. No rock of this character has been recognized within the limits of plate 4.

FIGURE 45.—Crenulated and metamorphosed rock of the Prichard formation on the trail to Lantern Lookout, north of the Hamilton quadrangle, Mont. The complexly folded, closely spaced parting planes coated with biotite are typical of this rock.

Beyond the area mapped by Langton and as far west as Lolo Pass (fig. 43), the principal rocks in contact with the batholith are thought by the writer to include representatives of the Prichard formation and components of the Ravalli group, probably belonging for the most part to the Appekunny formation. Farther northwest higher units of the Belt series appear. These correlations, which will be shown on the geologic map of Montana now in preparation, are based primarily on those of Langton. Because a large expanse of poorly mapped country stretches between Lolo Pass and the type locality of the Prichard slate (or formation) in Idaho (Ransome, 1905, pp. 280-281), some skepticism as to the validity of the correlation is justified. So far as the present report is concerned, the precise correlation is not of primary importance.

GRANITIC ROCKS OF THE IDAHO BATHOLITH

The entire western side of the quadrangle is underlain by the granitic rock of the Idaho batholith. So far as can be observed in the field, most of this rock is identical with that which is characteristic of most of the main mass of the batholith, a light-gray granitoid rock, moderately coarse grained, faintly gneissic, and of intermediate composition. Figure 46, a view taken just west of the Hamilton quadrangle, shows the typical appearance of the rock. The face against which the knife is resting shows the faintly laminated or gneissic texture. The gneissic appearance tends to increase eastward fairly uniformly until a narrow transition zone is reached between the essentially granitic rock and the border-zone gneiss. The interrelations of these granitic and gneissic rocks are further discussed in the following pages.

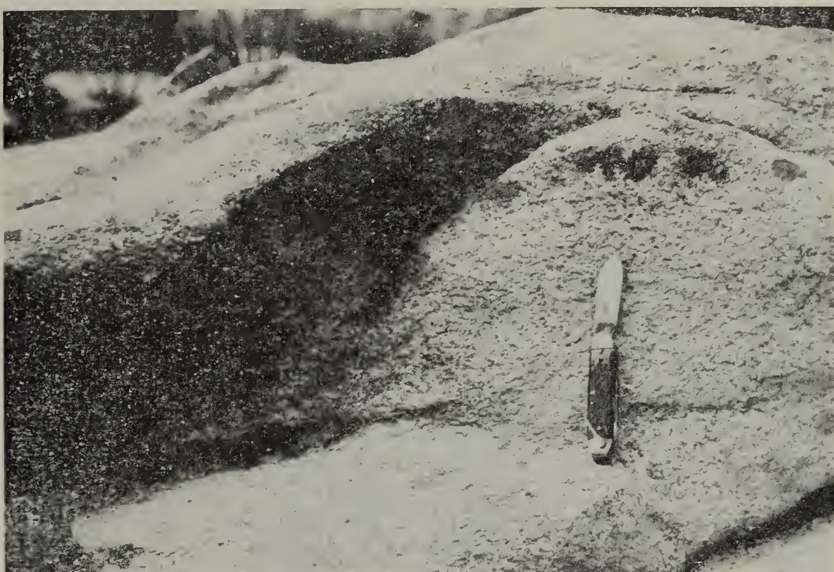

FIGURE 46.—Typical exposure of the granitic rock of the main part of the Idaho batholith in Bear Creek Pass at the head of Lost Horse Creek, just west of the Hamilton quadrangle, Mont., showing a faintly gneissic texture but no tendency to weather in slabs.

There are a few stringers of pegmatite and aplite in the granitic rock along upper Blodgett Creek and in other localities in and near the Hamilton quadrangle, but, as in most parts of the Idaho batholith, these are distinctly subordinate and are entirely absent over wide areas. In contrast, pegmatitic and aplitic material is fairly abundant near Lolo Pass (fig. 43).

The part of the main body of the Idaho batholith in and near the Hamilton quadrangle is quartz monzonite similar in composition and texture to rock typical of that body in other regions (Ross, 1936, pp. 373-374). It is a little more silicic than the average.

The essential constituents of the rock are quartz, orthoclase, oligoclase, and biotite. Myrmekite in small grains is widely but not very abundantly distributed. It was among the last minerals to form. Lindgren (1904, pp. 18-19) gives an analysis of the granitic rock on Mill Creek and calculates from it that the rock contains 28.73 percent quartz, 20.04 percent orthoclase molecule, 33.98 percent albite molecule and 8.36 percent anorthite molecule (combined, equivalent to 42.34 percent oligoclase), 8.03 percent biotite, and 0.76 percent minor constituents. Langton reports that typical material contains 33 percent quartz, 16 percent orthoclase, 41 percent oligoclase, and 10 percent biotite, which is in essential agreement with Lindgren's data. Some of the rock contains more quartz and orthoclase, with proportionately less oligoclase. Muscovite is present locally. Both Lindgren and Langton report the presence of perthitic intergrowths, and they regard apatite and zircon as among the principal accessory minerals. Magnetite is locally conspicuous. The alteration products, sericite and chlorite, are locally present but not abundant.

Under the microscope most of the rock has a typical granitoid texture, with the grains measuring as much as 2 and rarely 3.5 millimeters in diameter (figs. 47*A* and 47*C*). However, there are minor healed crush zones throughout the rock, as is illustrated by figure 47*B*, which is taken from the same thin section as figure 47*A* but is less highly magnified. The material of the crush zones is now thoroughly recrystallized, with interlocking boundaries between the grains of feldspar and quartz, some of which are elongate. It includes some myrmekite, which here, as in the main body of the rock, is apparently among the latest minerals to consolidate. The crush zones, plus a tendency for the long axes of some of the uncrushed mineral grains, especially the biotite flakes, to have a parallel arrangement, give the gneissic appearance to the rock. However, the gneissic texture is nowhere very marked and in places, as in the rock illustrated in figure 47*C*, is almost nonexistent. The presence of uncrushed myrmekite in the crush zones proves that the crushing took place prior to the final stages in the consolidation of the batholith. The rocks illustrated in figures 47*A*, 47*B*, and 47*C* and, in outcrop, in figure 46 are closely similar in essential respects, including the faintly gneissic texture, to the typical rocks of the Idaho batholith throughout central Idaho.

GRANITIC ROCKS OF OUTLYING MASSES

Most of the outlying granitic masses in the Hamilton quadrangle are east of the Bitterroot Valley. One small body in and near section 4, T. 7 N., R. 21 W., on the west side of the valley, is correlated with these. Langton mapped an apparently similar small mass, not seen during the present investigation, near Sweathouse Creek, within the

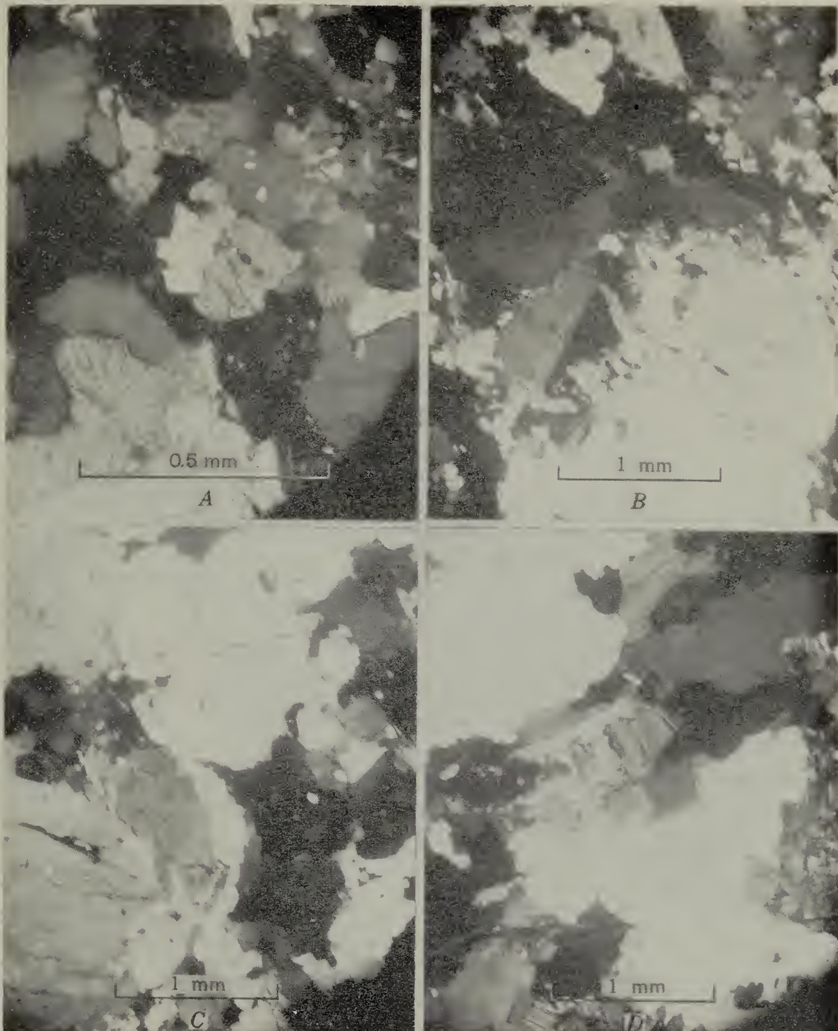

FIGURE 47.—Four photomicrographs showing different granitic rocks, all more or less gneissic, in or near the Hamilton quadrangle, Mont. Crossed nicols. *A*, A somewhat gneissic variety of the quartz monzonite of the Idaho batholith from the vicinity of Lost Horse Creek. *B*, The same rock as in *A* at a lower magnification, showing the healed crush zones that contribute to the gneissic texture. *C*, Quartz monzonite of the Idaho batholith from the neighborhood of Bear Creek. The magnification is the same as in *B*, but no crush zones are visible. *D*, Gneissic granite from the area east of Darby, a coarse, silicic rock with only slight evidence of crushing.

quadrangle. He also mapped about five others north of the quadrangle on both sides of Bitterroot Valley. All these outlying masses are far smaller than the Idaho batholith. The composition varies from that of granite to granodiorite and, exceptionally, diorite. The various granitic masses are regarded as forming part of the assemblage of intrusions, previously mentioned, intermediate in position and probably also in age between the Idaho batholith on the west and the Boulder batholith on the east. This agrees with Langton's suggestion that the masses he mapped are somewhat younger than the main part of the Idaho batholith.

Much of the component material of the outlying granitic masses within the Hamilton quadrangle is somewhat coarser and, at least in part, more silicic and potassic than the rock of the Idaho batholith. That examined in thin section (fig. 47*D*) contains abundant quartz, some microcline, fairly plentiful oligoclase or oligoclase-andesine, and biotite. The component grains are 1 to 4 millimeters long and tend to show crystal outlines more than those of the main batholith.

Langton's description (1935, p. 43) indicates that the stock near the southwest corner of T. 7 N., R. 19 W., is a quartz monzonite of variable composition, averaging about 35 percent quartz, 30 percent orthoclase, 32 percent oligoclase, less than 5 percent biotite, and a little muscovite, apatite, and zircon.

GNEISSIC GRANITE

The rock designated "gneissic granite" on plate 4 is a variant of the granitoid rock of the outlying masses just described. It constitutes a link between that rock and the injection gneiss to be described. In places these three rocks are gradational to such an extent that the boundaries mapped are necessarily somewhat arbitrary. The gneissic masses, like those of more granitoid texture, have a considerable range in composition. The component minerals are essentially the same, the distinction between the two kinds of rock being textural. In the gneissic granite the biotite tends to be concentrated in narrow, discontinuous laminae and the long axes of the larger quartz and feldspar grains are roughly parallel to these laminae. In both the granitic rock and gneissic granite, as mapped, the component grains interlock in the manner commonly regarded as characteristic of intrusive igneous rocks. Many are hypidiomorphic. The gneissic granite shows minor crush zones like those in the rock of the main batholith, but these are subordinate and inconspicuous.

Pegmatitic and aplitic dikes and stringers are more abundant in the gneissic granite than in any of the masses of more normal granitoid texture in the Hamilton quadrangle. In places, as along the lower reaches of Sleeping Child Creek, small dark schlieren are present, though nowhere very abundant.

INJECTION GNEISS

The main body of the injection gneiss mapped is in the drainage basin of Sleeping Child Creek and adjacent areas. The rock is somewhat heterogeneous, but most of it is characterized by light- and dark-gray laminae a few inches wide, glistening with biotite flakes and cut in places by more irregular stringers, most of which consist of light-colored crystalline material. The general appearance in the outcrop is that of a somewhat metamorphosed thin-bedded, sedimentary rock, containing dikelets of aplitic material. The rock has been extensively crumpled, but not as intricately as the Prichard formation farther northwest (fig. 45). The sedimentary rock from which the injection gneiss was derived was originally quartzitic and argillaceous in various proportions but, on the average, more quartzitic than the Prichard. Locally it has been so much fractured as to have become a breccia. On close examination in the outcrop, many of the laminae, as well as the crosscutting stringers, may be seen to have a crystalline texture and, some of them, the appearance of igneous rock. However, some bands and even entire outcrops are so little affected by the addition of igneous material that they are best described as dark, micaceous quartzite (originally probably an argillaceous sandstone). Most of the rock mapped on plate 4 as injection gneiss is represented on the geologic map of Montana issued in 1944 (Andrews, Lambert, and Stose, 1944) as belonging to the Ravalli group. Evidently, in the reconnaissance work on which the map was based in this part of the State, the sedimentary features of the injection gneiss seemed more impressive than those of igneous character.

Under the microscope the appearance of material from a representative lamina of the injection gneiss is that of a thoroughly crystalline rock. Most of the grains are without crystal outlines, and there is a tendency for the quartz and feldspar to have interlocking boundaries. Well over half the rock is quartz, and biotite makes up fully 20 percent. The remainder is feldspar, mainly a plagioclase of the approximate composition of oligoclase. The proportions of the different minerals doubtless vary widely in different laminae.

There seems to be little question that the injection gneiss is a sedimentary rock, thoroughly recrystallized, to which much material of igneous derivation has been added. The additions are thought to have been made in part by injection along bedding planes, in part by the filling of cracks and shatter zones, and in part by permeation of the rock. All three processes, but especially the last mentioned, would be expected to involve some interchange of the components of the original rock with those of the material that invaded it, in addition to the filling of open spaces by magma. The mode of origin of this injection gneiss is broadly similar to that of the rock that has been termed "injection gneiss" in the region drained by the Middle Fork Salmon River in central Idaho (Ross, 1934, pp. 42-45). There are resemblances in character and probable origin between the injection gneiss and parts of the border-zone gneiss and of the xenoliths and pendants in the Idaho batholith. The structural relations of these three units are distinctly different and cannot be traced into contact with each other. Age relations are not subject to precise determination, but it may be noted that the injection gneiss is genetically associated with granitic rocks that may be younger than the Idaho batholith. Hence it has seemed best to describe the three separately even though this procedure may appear to suggest greater differences than actually exist.

XENOLITHS AND PENDANTS

Langton (1935, pp. 41-43) maps and briefly describes several xenoliths and detached roof pendants in the Idaho batholith. One of these masses and part of another are within the area of plate 4. Langton says that most of the rock composing the xenoliths and pendants consists of quartzite, brown sandstone, and greenish metamorphosed limestone that have been subjected to extensive lit-par-lit injection and consequently have been tightly folded. Thus they resemble the injection gneiss east of Bitterroot Valley, although the structural relations are different. Langton says that a few of the xenoliths consist of what he terms "older gneiss." The fact that these are not specifically identified on his map suggests that the different kinds of gneiss in the xenoliths resemble or grade into each other sufficiently to make distinction in mapping difficult. He maps one xenolith nearly 9½ miles west of Florence as composed of Grinnell argillite and suggests that another consists of beds of the Grinnell or Appekunny and Newland (Wallace) formations, but the others are evidently so much metamorphosed that he was unable to suggest correlation with known stratigraphic units. In spite of the fact that the xenoliths show the effects of much lit-par-lit injection, Langton states that they exhibit little evidence of assimilation. On the contrary: "The xenoliths are exceedingly angular; and even small inclusions of quartzite, highly recrystallized, show no evidence of solution,—or of hybridism." Langton reports, however, as an unusual feature suggestive of hybridism, the presence of 5 percent sillimanite in one specimen near the contact of a xenolith.

The xenoliths and pendants mapped by Langton were not reached by any of the writer's traverses in the Hamilton quadrangle. The reported lack of assimilation or hybridism in these small masses surrounded by granitic rock is surprising in view of the record in other parts of the region. The description of the injection gneiss already given and that of the border-zone gneiss of the Idaho batholith which follows show that both contain more feldspar and other minerals of igneous aspect than would be expected through mere rearrangement of the chemical components of the rocks of the Belt series from which the gneisses are believed to have been derived.

In Idaho, west of Lolo Pass (fig. 43), there are xenoliths or pendants composed dominantly of sedimentary rock that contain more minerals resulting from metamorphism related to the Idaho batholith than Langton reported from the area he mapped. For example, in one such body in and near unsurveyed T. 38 N., R. 13 E., on the slopes of Blacklead Mountain, Anderson (1930, pp. 13, 42) noted the addition by this means of quartz, hornblende, epidote, and magnetite to a calcareous rock. Although it is not shown separately on his map, Anderson termed this rock the "Blacklead limestone" and thought it might be of Paleozoic age. An examination of the locality by the present writer in 1945, however, leads to the opinion that this highly metamorphosed limestone belongs to one of the more calcareous parts of the Belt series. It is thus comparable in origin to the xenoliths, also in part calcareous, in which Langton emphasizes the paucity of metamorphic minerals.

The part of Idaho from the vicinity of Lolo Pass westward past Blacklead Mountain is imperfectly known geologically. For this reason, and to some extent because of limitations imposed by scale, it is not adequately represented on the State geologic map (Ross and Forrester, 1947). Most of this area is shown on the map as underlain by the Idaho batholith, but part of the rock is known to be more gneissic than is typical of the main mass of that body. Detailed study would result in distinguishing xenoliths and roof pendants containing various kinds of gneiss, more or less similar to those described in the present report, as well as dikes of aplite and pegmatite and possibly other intrusive masses distinct from the main body of the batholith. Such study would add greatly to knowledge regarding the subject of this paper.

BORDER-ZONE GNEISS

The gneiss in the border of the Idaho batholith immediately west of Bitterroot Valley, as mapped on plate 4, includes only the rock that has a distinctly laminated or stratiform character; it does not include granitic rock which is gneissic only to the extent that minor crush zones are present and its component mineral grains are sufficiently parallel to give a vaguely laminated or gneissic appearance to the rock. Thus limited, the border-zone gneiss comprises only the eastern ends of the spurs of the Bitterroot Range. Lindgren's well-phrased description of the rock (1904, pp. 21-22) as exposed along Mill Creek is quoted with approval by Langton (1935, p. 41), whose interpretation of the origin is nevertheless quite different, as has been noted.

When the eastern slopes of the Bitterroot Range in the Hamilton quadrangle are viewed from a distance, the outer parts appear to be composed of rather massive but definitely laminated or stratified rock, whereas the rock closer to the range crest has no such appearance of stratification. Figure 46 illustrates this. Similar features are visible in figure 50, although less distinctly because it is a more general view. The topographic characteristics of the outer parts of the range have much in common with those of many of the mountains throughout western Montana that are carved on the more massive parts of the Belt series, particularly the Ravalli group of that series.

The impression that the rock of the outer slopes and spur ends is stratified persists and, in most localities on the border of Bitterroot Valley, is strengthened when the range is approached and finally entered along the numerous trails that branch from roads in the valley and reach to or beyond the canyon mouths. The rock that gives this impression is that which is here termed the "border-zone gneiss." In composition, and to some extent in texture also, this gneiss reminds the observer of a granitic rock; however, many of its broader characteristics are those of sedimentary rocks. In the field one is so constantly impressed by the resemblance to stratified rock, even in those parts of the gneiss in which feldspar is conspicuous and textures approach those of normal granitic rocks, that one comes to accept the lamination of the gneiss as a feature that has survived from an original sedimentary rock.

Figures 48-52 show some of these features of the rock. The major laminae are generally several inches to a foot or, rarely, somewhat more in width. They are subparallel but tend to lens out along the strike somewhat like the bedding in the quartzitic argillite and argillitic quartzite that make up much of the Belt series. In some places, notably on exposed ridge tops, the rock has weathered along parting planes parallel to the laminae. The resulting slabs tend to emphasize the appearance of a bedded rock, as can be seen from figure 48.

The same photograph illustrates a less common feature. Certain laminae, like those in the lower right-hand corner of figure 48, appear to be cross-bedded. This is nowhere a prominent feature. Where it is preserved, it may be only faintly visible in some laminae and not perceptible in others. Cross bedding is present in many parts of the Belt series and in the more massive units is almost as poorly defined as it is in the gneiss even in the absence of strong metamorphism.

FIGURE 48.—Border-zone gneiss of the Idaho batholith on the ridge crest above Lost Horse Creek, Hamilton quadrangle, Mont. This is a stratiform gneiss that weathers in slabs along the stratification planes.

FIGURE 49.—Ward Mountain from the vicinity of Hamilton, Mont. Such triangular facets, showing lines of stratification visible in the scarps, are common along the front of the Bitterroot Range.

949400—52—4

FIGURE 50.—The front of the Bitterroot Range from a hillock in sec. 11, T. 4 N., R. 21 W. (Hamilton quadrangle, Mont.), showing several triangular facets with lines of stratification on their sides.

FIGURE 51.—Border-zone gneiss of the Idaho batholith, with distinct parting planes, in the north wall of the canyon of Fred Burr Creek, Hamilton quadrangle, Mont.

FIGURE 52.—Close view of a block of gneiss from the border zone of the Idaho batholith, near the mouth of Fred Burr Creek, Hamilton quadrangle, Mont., showing the typical granitoid appearance and pseudophenocrysts.

On steep canyon walls the tendency to weather out in slabs is rarely so pronounced as in figure 48. In some places along these cliffs the lamination is visible only on close inspection. More commonly, however, enough weathering has occurred to produce exposures like that shown in figure 51. So far as might be judged from this photograph alone, the rock might well be a granite characterized by closely spaced joints of low dip. Closer views such as figure 52 show that the laminae are much closer spaced than the joints and that the rock is certainly not a normal granite.

Somewhat exceptionally, either the greater part of a canyon-side exposure or certain laminae in such an exposure are dark gray to black, corresponding mainly to a comparatively high biotite and chlorite content. The dark rock is generally finer-grained than the average. Rock of this sort, which is present in small exposures all along the range front within the area of plate 4, adds greatly to the sedimentary appearance of the outcrop. Some of these exposures—along the lower reaches of the canyon of Roaring Lion Creek, for example—have much the same general character as outcrops of the Appekunny formation along Rock Creek on the eastern border of the area Langton mapped (fig. 43) and in other localities in Montana where the rocks have not been affected by granitic intrusions.

949400—52—5

The features here regarded as stratification planes were thought of as shear planes by Lindgren, an interpretation which is supported by the presence of slickensides on many of them, especially in the southern part of the quadrangle. The slickensides are everywhere discontinuous and small. In many localities they are absent entirely. They seem best explained as the results of minor readjustments along planes of weakness between laminae of more or less different character.

In some outcrops the gneiss is cut by stringers and dikelets of aplite and granite. Some of these seem to spread out and give a granitic appearance to irregular areas several feet wide; others are narrow and sharply bounded. Lenticular and rounded pods also occur. The quantity of such material in the border zone is distinctly less than in the gneissic rocks east of Bitterroot Valley. In most areas on both sides of the valley the dikelets are subordinate features of the rocks.

Most of the border-zone gneiss within the mapped area is of broadly uniform composition and shows only minor variations in texture. The first impression gained from close inspection of many of the outcrops is that igneous features are conspicuous. Feldspar and micaceous minerals are plentiful, and many of the outcrops show textures closely resembling those of igneous rocks, either granitic or, more rarely, aplitic in character. Doubtless these were the features that caused Lindgren to assume that the rock was essentially a granite that had been deformed by crushing in a major fault zone. However, further examination reveals many features that are not in harmony with his idea. This is reflected in Lindgren's own statement (1904, p. 22) that in places "the whole imitates fairly successfully a fine-grained clastic rock." The truth appears to be that, instead of being an imitation, the rock is actually clastic, with some of its original features obscured by changes that have taken place during a long and complex history.

The greater part of the border-zone gneiss is a fairly uniform rock that varies mainly in the proportions of its constituents and in coarseness of grain. The principal minerals are quartz, potash feldspar, sodic plagioclase, biotite, other micas, and some myrmekite. A small part of the potash feldspar has distinct microcline twinning. So much of the rock is fine-grained, and the grains of quartz and feldspar are so intimately mingled with mica flakes, that accurate estimates of the composition are not feasible. In nearly all the gneiss, quartz is the principal component, especially in the groundmass, and in most of it this mineral probably constitutes 50 to 75 percent of the rock. Feldspar constitutes 15 to 35 percent, exceptionally more than 50 percent, and in most places potash feldspar appears to be more abundant than plagioclase. Most of the plagioclase has the composition of oligoclase, but in some of the rocks it is oligoclase-andesine. Most is remarkably fresh, but some is somewhat sericitized. Mica is everywhere present and may compose as much as half of some of the thinner laminae. Probably it does not constitute much more than 10 percent of the average rock. Much of the mica is pleochroic, greenish-brown biotite, but there is some muscovite and sericite, especially in the finer-grained rocks. Some of the micaceous material is chlorite. Myrmekite (an intricate intergrowth of quartz and plagioclase) is widespread but nowhere abundant. Probably it rarely exceeds 5 percent of the rock. Garnet, epidote, apatite, pyrite, and magnetite are locally present in very small amounts.

The general appearance under the microscope is that of a sedimentary rock that has undergone extensive recrystallization. Cross sections of laminae a few tenths of a millimeter wide are plainly visible, but few of the component grains have shapes suggestive of detrital origin. Figures 53*A* and 54*B* are photographs of thin sections cut across the laminae, which, however, are not as prominent in the photographs as they are under the microscope. The groundmass consists of interlocking or merging grains, commonly a few hundredths of a millimeter and, in exceptional instances, over 0.2 millimeter in greatest dimension, in which quartz commonly predominates. Thin, mica-rich lenses are fairly common, although they only rarely make up any large percentage of the rock. Where feldspar has crystallized in abundance, as in figure 53*C*, the original banding tends to be obscured.

In most places the groundmass is studded with pseudophenocrysts of quartz and feldspar which may be as much as 5 millimeters in length. Commonly the constituents of the groundmass and thin streaks composed of mica flakes tend to curve around the pseudophenocrysts, some of which have crushed borders. This is well illustrated in figure 53*D* and less distinctly in some of the other photomicrographs. Some of the plagioclase grains show the crystal form. Some lenticular aggregates, mostly composed of quartz, have the appearance of large, thoroughly crushed and recemented grains, and many of the unbroken quartz grains of all sizes and, less conspicuously, those of feldspar show strain shadows.

Seen in thin section, the pseudophenocrysts that have been mentioned correspond, except in size, to the large grains that stud rocks such as that illustrated in figures 51 and 52. These may be 50 millimeters or more in length. As figure 52 shows, they are so closely spaced that they tend to obscure the sedimentary features of the rock. Except for the close spacing and the tendency for the long axes to be parallel to each other and to the laminations in the groundmass, they give the rock the appearance of a porphyry. If phenocrysts, pebbles, or other grains significantly larger than the grains composing the

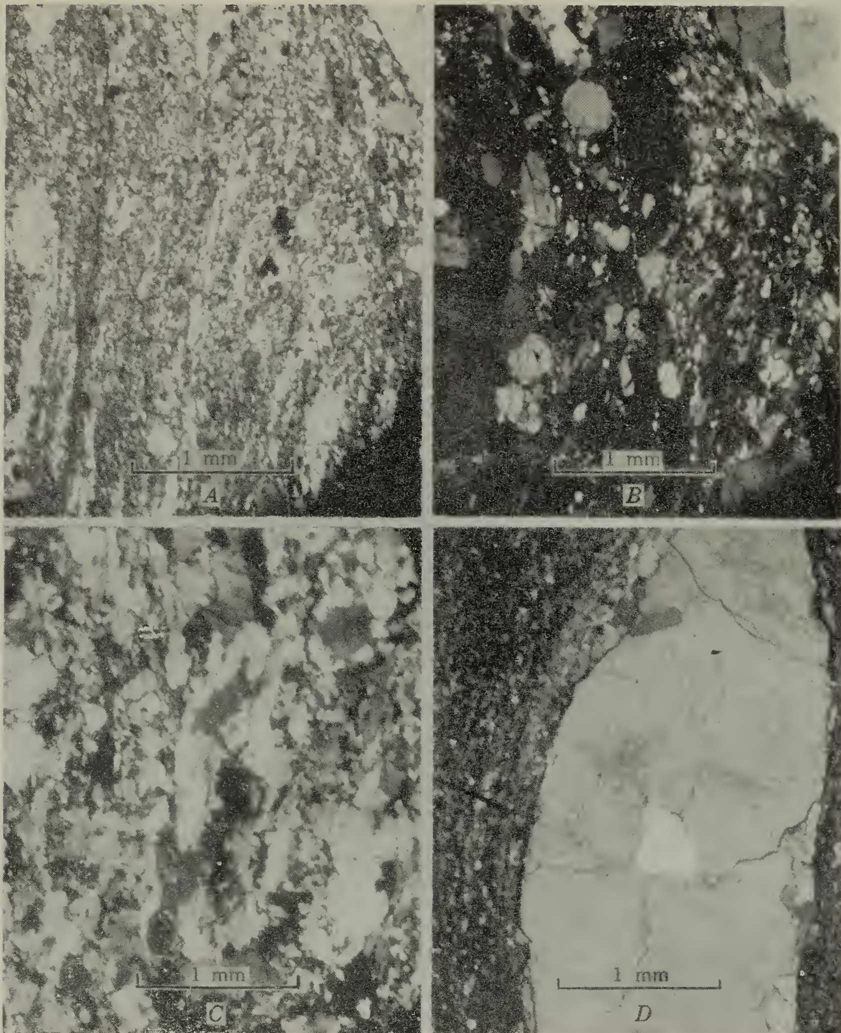

FIGURE 53.—Four photomicrographs showing varieties of gneiss from the border zone of the Idaho batholith, in or near the Hamilton quadrangle, Mont. *A*, A dark, distinctly banded variety of the gneiss occurring near the mouth of the canyon of Lost Horse Creek. *B*, A rather coarse gneiss from the vicinity of the Curlew mine. The bands have less tendency to curve around the pseudophenocrysts than is common. *C*, A variety of the gneiss, from the mouth of the canyon of Roaring Lion Creek, in which the original banding has begun to be obscured. *D*, A quartz pseudophenocryst in gneiss, found near the mouth of the canyon of Lost Horse Creek, with the thin bands of the groundmass curved around it.

groundmass were originally present in any of the rocks from which the border-zone gneiss was derived, they might have been preserved with only enough modification to make them difficult to distinguish from porphyroblasts of later origin. However, none of the unmetamorphosed Belt strata nearby include conglomerate, and none of the

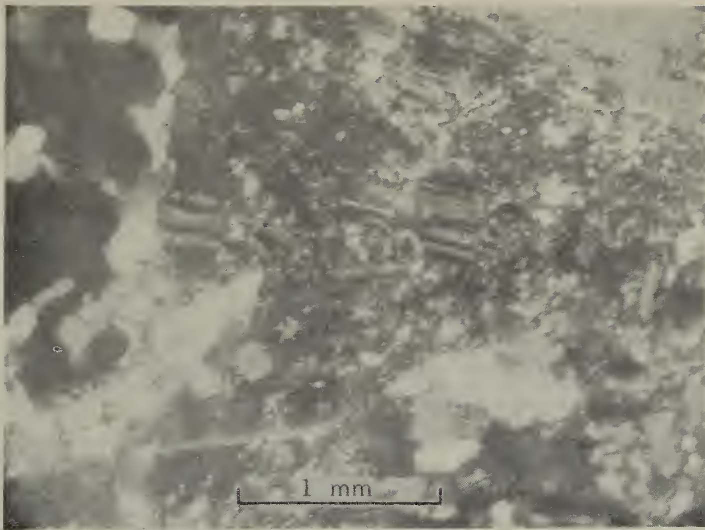

FIGURE 54.—Photomicrograph of quartzite in the gneiss from the border zone of the Idaho batholith near Gash Creek, Hamilton quadrangle, Mont. This is a thoroughly crushed and recemented rock, composed essentially of quartz with scattered grains of twinned plagioclase. Crossed nicols.

adjacent parts of the Idaho batholith are porphyritic. Even in areas such as those south of Lolo Pass in which the granitic rock does contain phenocrysts, they are not nearly so closely spaced nor so uniformly distributed as the large grains in the gneiss.

The evidence outlined makes it improbable that the pseudophenocrysts are survivals of grains of similar dimensions that existed prior to metamorphism. On the contrary, they appear to have formed during the extensive recrystallization to which the rocks have been subjected. This recrystallization was sufficiently extensive to obliterate all minor textural features such as individual grains, although broader features are preserved and are mainly responsible for the laminated character of the present rock. Recrystallization of this sort implies that fluids were circulating through the rock at the time it took place. Part of the constituents of the feldspars that were formed doubtless came from the original rock, but part must have been derived from the infiltrating fluids. These fluids may be supposed to have derived their constituents from the same magmatic source as the Idaho batholith, on whose borders they circulated. The processes were similar to those postulated for the gneiss along the Middle Fork Salmon River (Ross, 1934, pp. 42-45, 59-60), except that in the Bitterroot Range there is evidence of only one period of igneous metamorphism, whereas along the Middle Fork Salmon there were two different and widely spaced periods of granitic intrusion and accompanying metamorphism.

The descriptions here given apply, with minor variations, to approximately 90 percent of the border-zone gneiss within the mapped area. In a few places, however, particularly in the northern part of that area, rocks that are more obviously of sedimentary origin remain. The best examples noted are on the ridge between Bear and Gash Creeks, although there are similar exposures farther north. The rocks composing this ridge possess greater diversity in both attitude and composition than most of the rest of the border zone. Some of the outcrops consist of granitic material in which gneissic features are obscure, but many consist of rock readily recognized as of sedimentary origin. Most of the clearly sedimentary rock is quartzite, but some is argillaceous and one outcrop contains highly weathered, impure limestone. The quartzite is white to faintly greenish and, in some of the exposures near Gash Creek, intricately contorted. Under the microscope the rock is seen to consist of more than 90 percent quartz. The rest is mainly sodic plagioclase, with small amounts of chlorite, nearly colorless mica, and epidote. The quartz has been extensively and irregularly crushed and thoroughly recemented (fig. 54). In some of the quartzite comparatively well defined, narrow crush zones are at right angles to each other.

The argillaceous quartzite in an outcrop near Bear Creek (fig. 55)

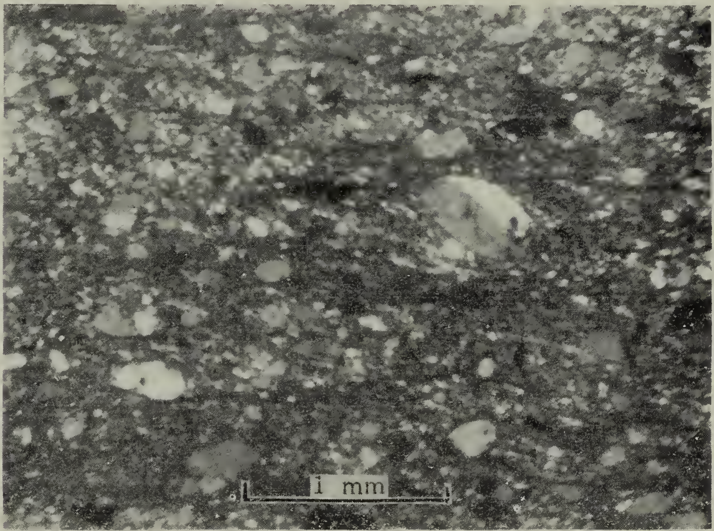

FIGURE 55.—Photomicrograph of argillaceous quartzite in the border-zone gneiss of the Idaho batholith near Bear Creek, Hamilton quadrangle, Mont. Note the well-rounded oval grains of quartz and twinned plagioclase in a finer-grained matrix containing micaceous material. Crossed nicols.

has retained some of the original well-rounded detrital grains unchanged, an unusual feature even in rocks of the Belt series at a distance from any batholith. It is a distinctly laminated fine-grained rock with oval grains of plagioclase and quartz up to a millimeter long scattered through a matrix in which the maximum dimensions of the grains are less than 0.05 millimeter. Some of these larger grains are partly surrounded by fragments frittered from them, and a few are partly or wholly crushed and recemented. The rock also contains pleochroic greenish-brown biotite, colorless micaceous material, and a little apatite, epidote, and pyrite.

It could be argued that the larger grains interpreted as being of detrital origin are really similar to the pseudophenocrysts already described and pictured in figure 53. On present evidence, this cannot be definitely disproved, but the shapes of the grains and their relation to the groundmass favor the interpretation of detrital origin. Detrital material of this size is to be expected in rocks of the Ravalli group, whereas closely spaced pebbles over an inch long would be surprising.

Those characteristics of the border-zone gneiss that tend to show igneous affinities increase westward until a narrow transition zone is reached. This is true both of general features and those observable only on close inspection. The contacts on plate 4 are at the transition zone, which is too narrow to be represented on a reconnaissance map, although in most places the zone is sufficiently well defined that the general position of the contact can be depicted on the map with confidence. West of this zone the rock is definitely granitic, although much of it is somewhat more gneissic in texture than is usual in the main mass of the batholith. This latter distinction is too slight and intangible to be mappable, except, perhaps, on the basis of very detailed work. Lindgren's descriptions (1904, pp. 21-23, 36-37, 43-47) show that he appreciated the presence of these changes in the rock toward the west, although his explanation differs from that offered here.

In summary, the rocks grouped on the map as the border-zone gneiss have broad similarities throughout but many variations in detail. They retain so many characteristics of sedimentary rock, both in general appearance and in their details of composition, that there seems to be no question that they are predominantly of sedimentary origin. The laminations that are visible in varying degree throughout the unit have the features to be expected in a sedimentary rock that was originally rather massive but has been subjected to metamorphism. In nearly all the rock, quartz is far too abundant for a normal igneous rock, and in places it is almost the sole essential constituent. The layers and larger masses of dark micaceous rock that are present in varying amount throughout the gneiss have the shapes, structural relations, and composition of thoroughly recrystallized and otherwise metamorphosed argillaceous rocks. They do not contain the minerals that would be expected in a metamorphosed igneous rock. In a few places, especially toward the northern part of the quadrangle, rocks that in composition and texture are of indubitable sedimentary origin have survived. It might be argued that these are inclusions of sedimentary rock in material of igneous origin, but in view of the general relationships seen and the gradations between rock with an obvious sedimentary texture and that which has been completely recrystallized, such a hypothesis is most improbable.

The concept that the metamorphism which has produced this gneiss is related to the intrusion of the Idaho batholith is inescapable. The structural relations of the border-zone gneiss, the fact that features of metasedimentary character decrease as the batholith is approached, and the presence in the gneiss of minerals akin to those of the rock that composes the greater part of the batholith all point in this direction. With the data at hand it is not possible to determine to what extent the feldspar and other minerals in the gneiss derive their constituents from the original rock and what proportion of these constituents has been introduced from fluids of magmatic origin. Undoubtedly both sources have been drawn upon. The fact that the plagioclase throughout the gneiss has approximately the same composition as the quartz monzonite of the batholith, as well as the presence of myrmekite in both rocks, strongly favors the idea that fluids from the batholith influenced the composition of the gneiss on its flank.

If the sedimentary origin of the border-zone gneiss is accepted, it is clear from data outlined in the early part of this report that the rock from which it was derived belonged to the Belt series. This conclusion is based both on the present distribution of sedimentary rocks of various kinds in the surrounding region and on the inferred character of the gneiss prior to metamorphism. Further, as the characteristics that survive in the gneiss show none of the features of the Missoula or Piegan groups of the Belt series but correspond more nearly to those of grayish, somewhat argillaceous quartzite such as is abundant in the Ravalli group, it is probable that the gneiss was derived from components of that group. The Ravalli group, especially the Appekunny formation, is extensively exposed in areas north of the Hamilton quadrangle. Rocks that have been assigned to the Prichard formation, which underlies the Ravalli group, also are widespread north and northwest of the quadrangle. These, however, commonly are extensively contorted (fig. 49), a feature which would survive and make them recognizable if any were included in the border-zone gneiss within the Hamilton quadrangle. The absence of rocks with closely spaced, highly contorted stratification planes in the border-zone gneiss suggests that no beds of the Prichard formation were present at the border of the batholith within the Hamilton quadrangle at the time that the gneiss was produced.

LANGTON'S YOUNGER AND OLDER GNEISS

On the eastern slopes of the Bitterroot Range Langton (1935, pp. 38-41) maps two belts of rocks parallel to the range front. He terms the outer belt "older gneiss." This belt corresponds broadly to the border-zone gneiss of the present report. The inner belt, termed "younger gneiss" by Langton, appears to be equivalent to the outer part of the main body of the Idaho batholith. Although this outer zone is, at least locally, slightly more gneissic than most of the batholith, such differences as were seen during the present investigation are so slight and ill-defined that no unit corresponding to Langton's younger gneiss has been distinguished on plate 4.

Langton quotes with approval Lindgren's well-phrased description of the gneiss along Mill Creek west of Corvallis but states that he "fails to agree with Lindgren that the rock is but the metamorphosed equivalent of the younger gneiss or the massive granite." He thinks it more probable that his older gneiss is the equivalent of an older true granite. Apparently his conclusion is based mainly on his determination under the microscope that specimens of the gneiss contained 45 percent orthoclase, 34 percent quartz, 13 percent oligoclase, 3 percent muscovite, and 5 percent biotite. As he indicates, a rock with such a composition would correspond more nearly to a granite in the strict sense of that term than to the quartz monzonite and granodiorite that compose most of the Idaho batholith. Much of the border-zone gneiss is far more silicic than that cited by Langton.

It is not clear why Langton assumed that his postulated "true granite" might be "much older" than the Idaho batholith. Mere difference in composition would not justify such an assumption, because parts of the Idaho batholith are as close to a granite in composition (Ross, 1927, p. 6; 1936, pp. 373-374) as the rock cited by Langton. He apparently did not base his inference on observed structural relations, for the only pertinent data he presents are contained in his statement that the contact between his older and younger gneiss "is fairly sharp and readily detected in some places, but in others there may be a gradational zone." If it is assumed that Langton's petrographic data are correct, the particular part of his older gneiss represented by those data may correspond to a part of the border-zone gneiss in which material of igneous derivation predominates.

As no mappable unit corresponding to Langton's younger gneiss has been recognized south of the area he mapped, the characteristics that caused him to discriminate between older and younger gneiss may fade out southward. Possibly his younger gneiss consists of material like that which is found in and close to the narrow transition zone between the border-zone gneiss and the main part of the batholith (pl. 4). Langton uses as synonymous with "younger gneiss" the term "schlieren gneiss," which could not be applied to any significant body of the rock on the eastern slopes of the Bitterroot Range along any of the traverses in the Hamilton quadrangle made during the present investigation. There are, however, scattered schlieren in the gneissic granite, particularly near Sleeping Child Creek, and schlieren are sufficiently abundant in parts of the border zone of the Idaho batholith in central Idaho that the term "schlieren gneiss" might be appropriate there.

STRUCTURE ALONG THE RANGE FRONT

In the present report structure will be considered only to the extent that it bears on the interpretation of the origin of the border-zone gneiss. The steep, straight eastern front of the Bitterroot Range where this gneiss is exposed has previously been interpreted as a result of faulting, although different observers have different ideas as to the character of the postulated faults. A satisfactory solution of the broad problems involved must await further information, involving the study of a region much larger than the Hamilton quadrangle. Nevertheless, the data outlined here cast serious doubt on any interpretation in which the character of the gneiss or the details of the topography carved on that rock are regarded as indicative of a fault along or close to the present range front.

Lindgren's original idea (1904, pp. 47-51) was "that the eastern front of the Bitterroot Range is determined by an enormous flat fault," probably of normal character and "involving at the same time downward movement of the hanging [wall] and upward movement of the foot." He thought that the total displacement was at least 20,000 feet along the dip of the fault plane. He regarded this plane as equivalent to the eastern slope of the range and as having an inclination of 15°-26° E. According to his interpretation, "the unusual feature in this dislocation is the intimate combination of actual fault planes with schistose structure." He thought of this feature as being fundamentally significant in the analysis of faulting in general and emphasized his belief that the fault could not have taken place at a depth of more than a few thousand feet. He expressly states that any attempt to place the formation of the schistosity, which he regards as produced during faulting, "at great depths from the surface must lead to wholly improbable depths of erosion and amplitude of the faulting movement." Lindgren also called attention to the low dip as an unusual feature for a large normal fault such as he visualized.

Lindgren (1904, pp. 48-49, 86-87) refers to faults at the old Curlew mine. One of these was followed downward for a vertical distance of 500 feet by the mine workings, now inaccessible. A body of galena ore was exposed along this fault, which has limestone and quartzite on the footwall and gravels containing carbonized wood on the hanging wall. The strike is approximately north and the dip 45° E. This information was obtained by Lindgren mainly from Thomas Cowan, one-time foreman of the mine. Lindgren says that the sedimentary rocks in the footwall are "cut by slipping planes, and a little higher up the narrow zone of limestone and quartzite borders along a fault contact toward the normal gneissoid zone" with a northerly strike. Lindgren adds: "Along this contact, far removed from mining operations, a fault took place in 1898, the downthrow being on the eastern side." When visited by Lindgren in the following year this fault was still visible for a distance of 1,500 feet along the strike. It had a downthrow of 1 to 2 feet.

Pardee (1950, p. 390) in 1936 obtained information from Henry Buker, a former miner, which agrees with that given by Cowan in regard to the fault in the mine workings. When visited in August 1946 by the present writer, the mine had been inactive for a year and little could be seen. The surface west of the shaft is largely covered by angular debris of probable glacial origin. The sedimentary rock exposed in pits is weathered and rusty and has been altered as a result of mineralization. It is broken by numerous fractures, many of which dip 70° E. Dips as low as 45° are less common.

Lindgren calls attention to the abnormally steep gradients of some of the streams where they leave the mountains and that of an escarpment near the mouth of the canyon of Carlton Creek, north of the area shown on plate 4. He regards these as evidence of faulting. However, similarly steep gradients near the mouths of streams have been recorded in localities in Idaho (Ross, 1935, p. 88; 1937, p. 97) and are very common in both Idaho and western Montana. In some places they result from glaciation, but more frequently they record recent regional rejuvenation as a result of which tributary streams have not had time to adjust themselves to the lowered channels of the main streams.

There are, as Lindgren notes, distinct escarpments along the borders of the Bitterroot Valley, but those observed during the present investigation are regarded as parts of terrace remnants. Most are partly or wholly underlain by semiconsolidated Tertiary or Quaternary deposits. Some are parallel to the streams that emerge from the mountains approximately perpendicular to the range front. One such scarp along Roaring Lion Creek is visible near the left border of figure 49. Farther to the right in the same view is a less distinct scarp roughly parallel to the main Bitterroot Valley. Figure 50 shows several similar scarps that seem clearly to be products of erosion.

The trenches and notches cited by Pardee were not noted during the present investigation. Pardee is an experienced observer of geomorphic features, and one cannot question his statements, but the features he mentions may be related to some such recent and minor movements as those that have disturbed the present surface at the Curlew mine. The mineralized fractures at that mine must be of Tertiary or late Mesozoic age, as there is no reason to suppose that galena ore bodies were deposited in this region in very late Tertiary or post-Tertiary time. The fact that one such ore body was found to have a hanging wall of gravel of Tertiary age or younger does not invalidate such a conclusion.

Similar relations between ore and slightly consolidated sedimentary beds of supposed Tertiary age have been reported by Umpleby (1913, pp. 115-118) in the Leadville mine near Leadore, Idaho. This contact is explored by a long drift which was still in good condition when the mine was visited by the present writer in 1940. The Paleozoic limestone in the footwall is tilted, hydrothermally altered, and weathered, in strong contrast to the fresh, nearly flat Tertiary beds of the hanging wall. The impression was gained that the Tertiary beds might have been deposited originally against the inclined surface of the faulted and mineralized Paleozoic strata, previously laid bare by erosion. The contact is nearly parallel to the bedding in the limestone, and the Tertiary sediments are coarser and less well rounded close to the contact than they are a short distance away from it. This latter fact led Umpleby to suggest that this contact is close to the margin of the basin in which the Tertiary sediments were originally laid down. Umpleby regarded the Tertiary sediments as lacustrine. He records crushed material, including fragments of galena, along the contact in support of his idea that the contact is on a fault, but nothing could be found during the writer's visit in 1940 to suggest that any large disturbance had occurred since the Tertiary beds were laid down. Minor slippage along a surface inclined at about 35° would account for all the evidence of movement that was visible.

Conditions in the Curlew mine must be judged from the descriptions given by miners and the scanty observations possible in slumped, shallow pits, but it seems quite possible, even probable, that such fracturing and displacement as may have occurred at and near the mine since the gravel was deposited resulted from minor movements of adjustment and landslip without necessary relation to disturbances of a magnitude sufficient to contribute materially to producing the mountain range.

Langton's discussion of the fault (1935, pp. 52-55, fig. 1) postulated by Lindgren is not entirely clear. He maps no such fault, but states that although his evidence for normal faulting does not agree entirely with that of Lindgren, "the general conclusion is the same." He speaks of "an unusually regular surface" that forms the eastern slope of the Bitterroot Range. He notes that this surface is on both igneous and sedimentary gneiss and "generally conforms closely in strike and dip with the slipping planes." He adds that "slickensides and striations on the surface give evidence of a movement usually parallel to the dip of the gneiss and the planes of movement," with "the strongest granulation and most closely massed slipping planes" at the base of the range. In a footnote, reference is made to "a granulated gneissic zone nearly 3,000 feet in thickness," a description that does not seem in accord with Langton's own description of the gneiss. Perhaps he thought of the granulation as a late feature imposed on the gneiss after it had been produced, but no such granulation subsequent to recrystallization was found during the present investigation.

Langton maps a hypothetical thrust fault, along the median portion of Bitterroot Valley over a mile east of the range front, which he seems to regard as having been formed prior to the intrusion of the Idaho batholith, but the reasoning that led to his tentative conclusions involves matters beyond the scope of the present paper. The problem of this supposed buried fault appears to have no bearing on the genesis of the border-zone gneiss or the topographic forms that have developed on that gneiss.

Pardee (1950, p. 390, pl. 1) shows a normal fault, by means of a dashed line, close to the border of the range and cites with approval Lindgren's ideas in regard to the attitude and character of the fault. Pardee relies mainly on topographic forms as evidence for the normal fault he postulates. He mentions trenches back of several foothills and notches in the spurs south of Roaring Lion Creek and Blodgett Creek as marking the trace of the fault, and he infers that a peneplain of late Tertiary age has been dislocated by the faulting. As already noted, however, Pardee is inclined to agree with the present writer that the gneiss of the border zone is a comparatively old feature, not directly related to any such recent faulting.

Observations made during the present investigation show that the border-zone gneiss west of the Bitterroot Valley constitutes a slab that dips east and is cut into numerous sections by the closely spaced canyons incised into the eastern front of the Bitterroot Range. Although marked local variations in attitude exist, especially near the northern and southern ends of the Hamilton quadrangle, most of the features here interpreted as planes strike N. 15°-40° E., with the average close to the lower figure, and the common dips are 15°-35° SE. The attitudes measured in outcrops of the gneiss are shown on plate 4. Some of the strike and dip symbols shown in the upper left-hand corner of that map are taken from Langton's map. It will be noted that where attitudes of gneissic laminae within the granitic rock of the Idaho batholith are distinct enough to have been recorded, they are much less consistent in direction than those in the border-zone gneiss. Measurements on the topographic map of the quadrangle show that the steep segments of the spur ends between the canyons mentioned are inclined at angles of 12°-35°, with the average somewhat more than 16°. Thus the triangular spur ends are essentially dip slopes on resistant rocks, as can be seen from figure 48, figure 51, and, less distinctly, figure 49 and figure 50. As plate 4 and the photographs just cited, especially figure 50, show, they have much of the appearance commonly attributed to triangular fault facets along a straight range front, but this appearance is not supported by other evidence. The situation here is similar to that in the Pahsimeroi Mountains in Idaho where a straight, faceted mountain front looks like a fault scarp but is interpreted as a result of erosion along the bedding planes in steeply inclined sedimentary rocks (Ross, 1937, pp. 73-74, 85, pl. 8*A*; 1947, pp. 1137-1139).

The explanation of the attitude of the gneiss slab that most simply and satisfactorily accounts for the known facts is that this slab is a part of the rocks that were invaded by the Idaho batholith and were both metamorphosed and domed during the intrusion (fig. 56). In a previous paper the writer (Ross, 1936, pp. 376-381) concluded that the Idaho batholith originally had a nearly flat roof and comparatively steep, outward-sloping sides. Emplacement is believed to have taken place actively, with uplift and folding of the sedimentary rocks, rather than by passive occupation of an opening provided by means not directly related to the intrusion. On this basis, the part of the border zone exposed in the Hamilton quadrangle would be about in the position where the flat top of the batholith merged with the steep eastern side. The dips recorded agree with the concept of simple doming during emplacement of the batholith, without faulting or other complexity. Invasion of the original sedimentary rocks by emanations from the magma, which led to the present petrographic character of the gneiss, began during the emplacement of the magma and may have continued for some time thereafter. It had, however, ceased long before the normal faulting postulated by Lindgren, Langton, and Pardee would have taken place. Any effects of such comparatively recent fault movements on the gneiss would have been recorded by the presence of open fractures or unhealed crush zones. The data summarized

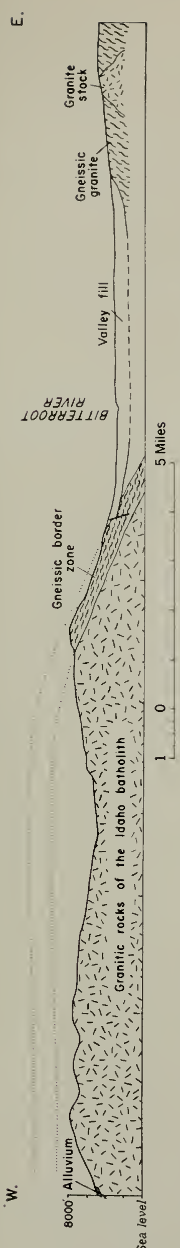

FIGURE 56.—Structure section along the northern border of T. 5 N., Hamilton quadrangle, Mont. (extended across the quadrangle), showing the interpretation of structure advocated in the present paper. A fault of slight throw that cuts the valley fill is indicated, but no inference is made as to the presence or absence of major faults concealed by the fill. Lindgren's interpretation, here rejected, was that the "gneissic border zone" shown is, instead, a crush zone along a normal fault of low dip.

indicate that the features of this kind which have been observed are all minor and inadequate as evidence of large-scale fault movements.

The structure section in figure 56 shows the interpretation of the structure just given. It extends in an easterly direction across the Hamilton quadrangle along the northern boundary of the fifth tier of townships north of the base line. In this section a minor normal fault similar to those known to exist at the Curlew mine has been indicated. No such fault has been proved to exist at the place represented in the section, but minor fractures are probably present at various places along the range front.

It seems clear that Lindgren's concept of a fault of large displacement that was a major factor in the origin of the border-zone gneiss is not acceptable. Even Langton and Pardee, who regard the topographic form of the range front as indicative of a large normal fault, raise queries as to Lindgren's concept of the origin of the gneiss. However, the presence of small, recent normal faults along the range front is proved by conditions at the Curlew mine and supported by Pardee's observations in regard to trenches and notched spurs. The question as to whether a long, buried fault of some kind underlies the alluvium of Bitterroot Valley is left open. The mere existence of a large, elongate valley, floored with detrital material, is not regarded as proof of faulting. As the triangular spur ends along the range front are dip slopes on a resistant rock, their value as evidence of faulting is eliminated. Evidence as to whether there is a buried fault must be sought by study of a broader region than the Hamilton quadrangle. Published data on adjacent areas are inadequate for the purpose.

CONCLUSIONS

Critical examination of the border-zone gneiss, both in the field and under the microscope, leads to the conclusion that the evidence of its origin as a sedimentary rock is preponderant. Certainly minerals and textures with igneous characteristics are present throughout the gneiss, but these seem everywhere to have been superimposed on features of sedimentary origin. The resemblance to a granitic rock is superficial and, in most of the gneiss, largely disappears on microscopic examination. This resemblance does, however, arise from incidents of great importance in the geologic history of the region. The original sedimentary rock was intruded by the Idaho batholith and, during the long course of this intrusion, was invaded by emanations that originated in the magma. Doubtless the emanations that permeated the sedimentary rock and caused the development in it of feldspars and other minerals of igneous aspect were more tenuous fluids than those that resulted in the filling of open fractures by dikes and more irregular masses of aplite and related rocks.

The rock shows, as Lindgren observed, evidence of widespread fracturing, but the fractures have been so thoroughly healed and the constituents of the rock so recrystallized and recemented that they cannot be cited as evidence of such a geologically young fault as has been suggested. Rather, this fracturing is to be attributed to forces exerted as the great mass of the batholith came into place and to adjustments required as a result of permeation of the original sedimentary rock by emanations that gave rise to new constituents and rearrangement among those that survived comparatively unchanged. The minor slickensides on stratification planes are different from the healed fractures within the now-recrystallized rock, in that they do record displacements of masses of the gneiss that occurred after the rock assumed its present character. The sum of the movements along these tiny, though numerous, fractures cannot represent any really large aggregate displacement. They are more likely to have resulted from late-stage readjustments after recrystallization had reached or approached completion. These readjustments presumably took place before or soon after the beginning of the Tertiary, rather than during or subsequent to the Pleistocene.

In view of these ideas as to the character of the rocks, the evidence for such a large and unusual fault as that postulated by Lindgren becomes completely inadequate. The structural and geomorphic features along the eastern front of the Bitterroot Range in the Hamilton quadrangle cannot be regarded as proof of large-scale faulting. On the contrary, these features result from differential erosion of rocks of differing degrees of resistance along a part of the border of the Idaho batholith. This conclusion is independent of such unsolved problems as that of the position and character of a possible fault or faults buried under the alluvium of Bitterroot Valley. The small recent fractures at the Curlew mine might be related in some way to the possible large fault in the valley, but they do not parallel in either strike or dip the major fault postulated by Lindgren. Whether or not the interpretations here advocated are accepted, the data presented may serve as a warning against too ready acceptance of a steep and moderately straight range front as proof of the presence of a fault.

REFERENCES CITED

ANDERSON, A. L., 1930, Geology and mineral resources of the region about Orofino, Idaho: Idaho Bur. Mines and Geology Pamphlet 34.

———, 1942, Endomorphism of the Idaho batholith: Geol. Soc. America Bull., vol. 53, no. 8, pp. 1099-1126.

ANDREWS, D. A., LAMBERT, G. S., and STOSE, G. W., 1944, Geologic map of Montana: U. S. Geol. Survey Oil and Gas Investigations Preliminary Map 25, sheet 2.

BECKER, G. F., 1885, Geological sketch of the Pacific division, chapter 1 in Statistics and technology of the precious metals: Tenth Census of the United States, 1880, vol. 13, pp. 52-54.

BELL, R. N., 1902(?), An outline of Idaho geology and of the principal ore deposits of Lemhi and Custer Counties, Idaho: Am. Min. Cong., Proc. 4th Assembly (Boise, Idaho, July 1901), pp. 65-66.

BILLINGSLEY, PAUL, 1916, The Boulder batholith of Montana: Am. Inst. Min. Eng. Trans., vol. 51, pp. 31-56.

CALKINS, F. C., 1930, The granitic rocks of the Yosemite region, in Matthes, F. E., Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160.

CALKINS, F. C., and EMMONS, W. H., 1915, U. S. Geol. Survey Geol. Atlas, Philipsburg folio (no. 196).

CLOOS, ERNST, 1932, Structural survey of the granodiorite south of Mariposa, Calif.: Am. Jour. Sci., 5th ser., vol. 23, pp. 289-304.

———, 1933, Structure of the Sierra Nevada batholith: 16th Internat. Geol. Cong. Guidebook 16.

———, 1935, Mother Lode and Sierra Nevada batholiths: Jour. Geology, vol. 43, no. 3, pp. 225-249.

DAVIDSON, DONALD, 1939, Geology and petrology of the Mineral Hill district, Idaho, in Summaries of Ph.D. theses, University of Minnesota, vol. 1, p. 212, University of Minnesota Press.

ELDRIDGE, G. H., 1895, A geological reconnaissance across Idaho: U. S. Geol. Survey 16th Ann. Rept., pt. 2, pp. 211-276.

GROUT, F. F., and BALK, ROBERT, 1934, Internal structures in the Boulder batholith: Geol. Soc. America Bull., vol. 45, pp. 877-896.

Klepper, M. R., 1950, A geological reconnaissance of parts of Beaverhead and Madison Counties, Mont.: U. S. Geol. Survey Bull. 969-C.

Langton, C. M., 1935, Geology of the northeastern part of the Idaho batholith and adjacent region in Montana: Jour. Geology, vol. 43, no. 1, pp. 27-60.

Lindgren, Waldemar, 1899, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey 20th Ann. Rept., pt. 3, pp. 65-256.

———, 1904, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27.

Pardee, J. T., 1950, Late Cenozoic block faulting in western Montana: Geol. Soc. America Bull., vol. 61, no. 4, pp. 359-406.

Ransome, F. L., 1905, Ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Bull. 260, pp. 274-303.

Ross, C. P., 1927, The Vienna district, Blaine County, Idaho: Idaho Bur. Mines and Geology Pamphlet 21.

———, 1934, Geology and ore deposits of the Casto quadrangle, Idaho: U. S. Geol. Survey Bull. 854.

———, 1936, Some features of the Idaho batholith: 16th Internat. Geol. Cong. (1933) Rept., vol. 1, pp. 369-385.

———, 1937, Geology and ore deposits of the Bayhorse region, Custer County, Idaho: U. S. Geol. Survey Bull. 877.

———, 1947a, Geology of the Borah Peak quadrangle, Idaho: Geol. Soc. America Bull., vol. 58, no. 12, pt. 1, pp. 1085-1160.

———, 1947b, Structure of the front of the Bitterroot Range, Mont. (abstract): Washington Acad. Sci. Jour., vol. 37, no. 10, p. 375.

———, 1947c, Eastern front of the Bitterroot Range near Hamilton, Mont. (abstract): Geol. Soc. America Bull., vol. 58, no. 12, pt. 2, pp. 1222-1223.

———, 1949, The Belt problem (abstract): Washington Acad. Sci. Jour., vol. 30, no. 3, pp. 111-113.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the State of Idaho (scale 1:500,000), U. S. Geological Survey.

Umpleby, J. B., 1913, Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528.

INDEX

Contributions to General Geology 1950

GEOLOGICAL SURVEY BULLETIN 974

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1952

UNITED STATES DEPARTMENT OF THE INTERIOR

Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the papers for separate publication]

ILLUSTRATIONS

☆U. S. GOVERNMENT PRINTING OFFICE: 1952—949400