GEOLOGY AND MINERAL RESOURCES OF THE NORTH FORK QUADRANGLE,
LEMHI COUNTY, IDAHO

by

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IDAHO BUREAU OF MINES AND GEOLOGY
MOSCOW, IDAHO
FOREWORD

In this present report Dr. Anderson completes the study of the geology and mineral resources of the third quadrangle in a continuing project of this Bureau, designed to map and explore the mineral potential of a large part of Lemhi County. As the mapping and study of each quadrangle (a convenient mapping unit) is completed the results are published, for it would obviously take too many pages to write and too many years to reach the public were we to attempt to complete the entire project before releasing the information obtained. On the other hand, publication as we go has its problems too: Dr. Anderson is already revising the first map issued in this series (Salmon quadrangle), for instance.

Mineral exploration, as well as decisions affecting regulation of natural resource use, can be intelligently based only on a knowledge of the disposition of geologic formations and structures favorable to the localization of economic mineral deposits. To obtain such knowledge requires geologic mapping and study of large areas. This type of project is being carried out in Lemhi County under the able direction of Dr. Anderson.

E. F. COOK, Director
Idaho Bureau of Mines & Geology
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The North Fork quadrangle covers the northern end of the Salmon Basin and the bordering slopes of the Beaverhead Range and Salmon River Mountains. Except for two small granitic stocks, one on each slope, the mountains are carved largely in the Lemhi and Swaner quartzites, thick members of the Precambrian Belt Series. The basin is floored by five unconformable Tertiary formations ranging from Eocene (or Paleocene) to middle Miocene; namely, the Kriley, Challis Volcanics, Kenney, Geertsan, and Kirtley Formations.

The Precambrian rocks have been complexly folded and faulted. Early in the Laramide orogeny, they were deformed into broad northeasterly-trending folds. Later, they were subjected to stronger forces from a southwesterly direction with superposition of prominent northwestward-trending folds, low-angle thrusts, high-angle thrusts, and high-angle normal faults on the earlier northeast structures.

After accumulation of the Challis Volcanics on a deeply dissected early Tertiary erosion surface, normal faulting blocked out the ancestral Salmon Basin and provided for the accumulation of the three younger Tertiary formations. Uplift of a Pleocene erosion surface at the close of the Tertiary resulted in the diversion of the northeasterly flowing Salmon River west to the Snake and Columbia Rivers, and provided the setting for the formation of ice caps on the mountain summits during the Pleistocene.

Mineral resources include small gold-quartz veins and lodes; large, low-grade, galena-bearing quartz lodes; small thorite replacement lodes; and extensive gravel deposits.
OUTLINE OF THE REPORT

This report on the geology and mineral resources of the North Fork quadrangle is the fourth of a series in a continuing investigation of the geology and mineral resources of the greater Salmon region. The quadrangle covers some 200 square miles of northern Lemhi County directly north of the Salmon quadrangle. It includes within its borders the eastern slope of the Salmon River Mountains, a northerly embayment of the Salmon Basin, and a sizeable part of the Beaverhead Range. The Quadrangle is drained by the Salmon River and its tributaries.

The rocks of the quadrangle are restricted to the Precambrian Belt Series, to the Challis Volcanics and four sedimentary formations of Tertiary age, to various kinds of Quaternary surficial deposits, and to some igneous rocks intruded at the close of Cretaceous and during mid-Tertiary time. The Precambrian rocks compose much of the rock of the mountainous parts of the quadrangle. The Tertiary stratified rocks, except the Challis Volcanics, are confined entirely to the Salmon Basin.

The thick and widespread Belt series is divisible into two formations, which appear to be equivalent to the Lemhi and Swaeger Quartzites in the Borah Peak quadrangle. The Lemhi Quartzite, the older of the two, occurs largely as impure, dark-colored beds, which are widespread from the Salmon River Mountain slope eastward to the Beaverhead Range, and locally in a part of the Beaverhead Range itself. The Swaeger Quartzite characteristically occurs as rather pure, light-colored beds, which are extensively developed throughout the northern part of the Beaverhead Range. They are exposed over more of the quadrangle than any other formation.

The best and most widely known of the Tertiary formations, the Challis Volcanics, are represented by dacitic, andesitic, and rhyolitic flows, and by light-colored pyroclastics, including bedded tuffs and welded tuffs (ignimbrites). The closely-associated, sedimentary formations include one that is older than and occurs unconformably beneath the Challis. This formation, mostly a thick conglomerate resting unconformably on the Belt rocks, is named the Kriley Formation. It was probably deposited at the close of Cretaceous or in early Tertiary (Eocene) time. The other sedimentary formations lie unconformably above the Challis and include the Kenney, Geertson, and Kirtley (formerly the Carmen), these last three of which were originally found and named in the Baker quadrangle. The several formations are separated by marked angular unconformities. Though the Tertiary rocks have not been accurately dated, the Kirtley Formation is known to be middle Miocene or younger, whereas the Challis are probably Oligocene, and the Kenney and Geertson are presumably late Oligocene and lower Miocene.

The Quaternary rocks include older, pre-Wisconsin glacial deposits occurring as ridge caps on the lower mountain slopes;
younger, Wisconsin glacial deposits, including till in the upper valleys of the higher mountains and terraced outwash trains in the lower valleys. Recent alluvium occurs along the valley floors of the Salmon River and its larger tributaries.

The intrusive rocks are found within the areas of the Precambrian rocks. The earlier intrusives include a body of altered gabbro and a granodiorite stock along or near the frontal slope of the Beaverhead Range, a quartz monzonite stock on the Salmon River Mountain slope, and a few small, inconspicuous lamprophyric dikes. The younger intrusives are represented by small masses of dacite porphyry, probably related to the flows in the Challis Volcanics; and by small bodies of quartz monzonite granophyre, probably younger than the Challis Volcanics.

All but the Quaternary rocks show marked effects of structural disturbances. The Precambrian rocks have been complexly folded and faulted, apparently by forces active during the Laramide orogeny at the close of Cretaceous time. Local evidence of prior, late Precambrian or early Paleozoic crustal disturbance has been obliterated. During the Laramide orogeny the Belt rocks, which had been first acted upon by northwest-southeast forces, were compressed into rather broad northeast-trending folds overturned toward the southeast. This activity may have resulted in the deposition of the coarse, conglomerate beds of the Kriley Formation. But a realignment of forces to the southwest-northeast then produced northwest folding and low- and high-angle overthrusting to the northeast, with development of regional northwest cleavage dipping always southwest at a moderate angle. Extensive normal faulting followed, especially along a zone parallel to the front of the Beaverhead Range. Later movement along these faults probably had much to do in initiating and maintaining the Salmon Basin in which the Tertiary sediments accumulated.

The relations of the Tertiary formations indicate considerable structural unrest throughout much of the early and middle part of the Tertiary. The Tertiary formations, separated by sharp, angular unconformities, show fold trends indicative of directional changes in force. Each crustal disturbance was apparently accompanied by renewed movement along the earlier faults. Later crustal movement involved chiefly differential uplift, particularly at the close of the Tertiary.

The geomorphic record indicates extensive erosion during and after the Laramide orogeny, with the formation of an old erosion surface during early Tertiary time. This erosion surface was rather deeply dissected before the extrusion of the Challis Volcanics. Erosion subsequently cut local surfaces of gentle-to-moderate relief on the Challis and similar surfaces successively on each of the younger Tertiary formations. By the end of the Tertiary the entire region had been bevelled by a Pliocene erosion surface.

Before Challis volcanism and during the deposition of the Tertiary sedimentary beds, the quadrangle's drainage had been apparently
to the southeast. With completion of the Pliocene erosion surface, the drainage was adjusted to the northeast, with the Salmon River flowing northeastward across what is now the north end of the Beaverhead Range and on into Montana. Uplift of the erosion surface and renewal of erosive activity at the close of the Tertiary resulted in the capture of the Salmon River by a vigorous stream working headward from the west and the diversion of Salmon's waters to the Snake and Columbia rivers. The uplift at that time also initiated the salient features of the present topography, giving shape to the Beaverhead Range, the Salmon River Mountains, and the Salmon Basin.

After the mountain groups and the intervening basin had become fairly well established, early Pleistocene glaciers capped the Salmon River Mountains and the Beaverhead Range, sending tongues of ice down their slopes onto the flanks of the basin. The melting ice left an accumulation of till and outwash material. After the glacier disappeared, there was as much as 1,000 feet of canyon cutting, probably in response to renewed uplift, during which the floor of the basin was dissected into its present hilly form. In late Pleistocene or Wisconsin time glaciers reappeared in the higher mountains and moved down the valleys but not as far as the earlier ones. These later glaciers left the higher mountains with their present glacial sculpture.

The late glaciers fed a vast amount of debris to the streams, which caused extensive filling of valley bottoms. After the ice melted, the less heavily debris-laden streams removed part of the valley fill, remnants of which remain as terraces bordering the present valley floors. Most of the streams are still actively engaged in canyon cutting.

Though the quadrangle does not have an impressive record of mineral production, its mineral resources include gold, lead, thorium, and gravel. The gold deposits are represented by generally small, shallow gold-quartz veins and lodes, and by small placers. The veins and lodes, chiefly fillings along complex fissure and fracture zones, are composed largely of quartz with small, variable amounts of pyrite, and locally, with a little galena and chalcopyrite. The gold has a spotty distribution, but in places forms small, rich shoots. The veins show a greater concentration in the vicinity of the quartz monzonite stock, and with one exception, are apparently associated genetically with the earlier igneous activity.

The lead deposits differ from the gold deposits in size and in the somewhat greater concentration of galena. The deposits, from tens of feet to 100 feet or more thick, are fillings and replacements along extensive zones of brecciated and otherwise greatly fractured rock. The chief mineral is quartz, accompanied in places by small, variable amounts of galena, and usually by some sphalerite, pyrite, and chalcopyrite as well. The galena, in disseminated grains and small granules, forms in places sizeable bodies of low-grade ore with probably less than 2 percent lead.
These deposits are closely related to the gold-quartz veins in the Beaverhead Range.

The thorium deposits, only recently known, have not been much explored. They are restricted to a small area on the Salmon River Mountain slope, mainly near Diamond Creek. They comprise small, mineralized shear zones and quartz veins with appreciable concentration of thorite and rare earth elements. The minerals associated with the thorite include monazite, xenotime(?), apatite, specular hematite, barite, fluorite, feldspar, and quartz. Few of these minerals can be distinguished without the microscope.

The gravel resources are practically unlimited; gravel is available in the several terraces, along the floors of the major stream valleys, in small fan deposits at the mouths of gulches bordering the main valley floors, and in outcrops of the weathered Kenney and Geertson Formations.
INTRODUCTION

PURPOSE AND SCOPE

This report on the North Fork quadrangle is another in the comprehensive investigation of the geology and mineral resources of the region surrounding Salmon, Idaho. This investigation, initiated in 1954 with study of the Salmon quadrangle (Anderson, 1956), was continued in 1955 and 1956 with work on the Baker (Anderson, 1957) and Leesburg (Shockey, 1957) quadrangles; and in 1957 and 1958, on the North Fork quadrangle.

Although designed to cover all aspects of the geology and mineralization in the Salmon region, the program of study had to be modified somewhat for each of the quadrangles. In the Salmon quadrangle the main emphasis was on the mineral deposits, which reduced stratigraphic and structural studies to a general reconnaissance. Consequently, no attempt was made at that time to subdivide the Belt Series, whose quartzitic rocks compose most of the mountainous parts of the area; nor was anything done with the "lake beds" of the basin area, other than to remove them from the Challis Volcanics and map them collectively as the Carmen Formation. In the Baker quadrangle, with its less impressive record of mineral production, less time was needed for the study of the mineral deposits and correspondingly more time was available for other phases of the geology. During that study it was possible to subdivide the "lake beds" into three unconformable formations, each of which was mapped separately; and to note that the Belt strata could be resolved into two distinctive formations, although the available time did not permit this to be done. Because of the rugged terrain and the limited time available for field investigation, the Leesburg quadrangle was covered by detailed reconnaissance, with emphasis on the genesis, stratigraphy, and structure of the Belt and Ordovician rocks, a study fundamental to any broad regional investigation. The time required for this work permitted little more than cursory examination and study of the mineralization.

In the North Fork quadrangle, where a scattering of mineral deposits required not much time to examine, the bedrock geology received considerably more attention than had been possible in either the Salmon or Baker quadrangles, though the study still had to be limited to a more or less detailed reconnaissance. At this time it was possible to separate the Belt into two mappable units and to single out one of these units for further subdivision. It was also possible to examine further the structural relations of these older rocks and to obtain data with regional implications, particularly with reference to the origin of the Salmon Basin and the Beaverhead Range. Unlike those of the Baker quadrangle, the "lake beds" could be assigned to four rather than three unconformable formations, the fourth older than the Challis Volcanics.
FIELDWORK AND ACKNOWLEDGMENTS

Except for several weeks spent in delineating and mapping the Tertiary formations in the lower parts of the quadrangle in 1957, the bulk of the fieldwork was carried on during the summer of 1938. This later work was largely confined to mapping and studying the older rocks in the higher mountains.

During the field studies the lack of a suitable base map made it necessary to resort to air photographs as a base for geologic mapping. The data placed on the photos were later transferred to a planimetric map of the North Fork quadrangle. This planimetric map, which shows drainage but not topography, was prepared by the U. S. Forest Service from air photos on a scale of 1:31,680. The map afforded an excellent base for geologic mapping and is reproduced, with some elimination of drainage details, as the base for the published geologic map.

Study of the quadrangle was impeded by a difficult terrain of steep, deeply-cut canyons in a setting of high, rugged mountains with heavy brush and timber growth on upper slopes. Much of the quadrangle has poor rock exposures and limited number of access roads and trails, making parts of the area difficult to reach and traversable only along the ridges.

During the first field season I was capably assisted by Mr. Bruce Brogoitti, student at the University of Idaho College of Mines; and during the second season, by Mr. Terrence McGurk, graduate student at the University of Idaho College of Mines. To both men I wish to express deep gratitude and appreciation for their services. During both summers I was accompanied by my teenage son, who also performed useful services.

PREVIOUS GEOLOGIC WORK

Because the quadrangle has received little attention prior to the present investigation, few published data exist on its geology and mineral resources. Unpleby (1913) included the area in his geologic sketch map prepared during his investigation of the ore deposits in Lemhi County in 1910 but made no specific mention of the geology and mineral deposits within the area itself. MacKenzie (1949) studied and described a small part of the quadrangle east of Carmen Creek in 1948 as a part of his thesis investigation for a Master's Degree at the University of Idaho. In his report, which is on file in the library of the University of Idaho College of Mines, he has distinguished between two unlike lithologic facies of the Belt Series and mapped each separately. These facies are now correlated with the Lemhi and Swauger Quartzites. He also mapped and described part of the granodiorite stock along Carmen Creek. Some of the data from his map have been incorporated in the present report. The thorite deposits in the Diamond Creek area were investigated during the summer of 1937 and the results of the investigation published in 1938 (Anderson, 1938).
Fig. 1. Index map showing the location of the North Fork quadrangle (N) with reference to the Salmon (S), Leesburg (L), and Baker (B) quadrangles.
A. NORTH FORK

Settlement of North Fork at the junction of the North Fork of the Salmon River with the main river. The view is up the Salmon River toward the Salmon Basin. U.S. Highway 93 shown along the river.

B. BASIN AND RANGE SETTING OF THE SOUTH PART OF THE NORTH FORK QUADRANGLE

Hilly surface of the Salmon Basin and the wide valley floor of the Salmon River and Carmen Creek, with the Beaverhead Range rising boldly above the basin in the background. Narrow hilly ridge between the river and Carmen Creek is composed of the Kirtley formation. Higher hills in front of the range are carved in the Kenney formation. Picture taken from the dissected Salmon River Mountain slope.
GEOGRAPHY

LOCATION

Although the North Fork quadrangle extends a short distance across the Continental Divide into Montana, more than 96 percent of its area is in Idaho in the northern part of Lemhi County (fig. 1). It borders on the north side of the Salmon quadrangle and corners on both the Baker and Leesburg quadrangles. It is bounded by parallels 45° 15' and 45° 30' north latitude and by meridians 113° 45' and 114° 00' west longitude. The quadrangle measures a little over 17½ miles north and south and about 12½ miles east and west, covering altogether about 212 square miles, of which all but about 7 square miles are in Idaho. The area in this quadrangle is included in part or in whole in Ts. 22, 23, 24, and 25 N., and Rs. 21, 22, and 23 E., Boise meridian. Much of its area is within the borders of the Salmon National Forest (pl. 1).

SURFACE FEATURES

Physiographic setting

The physiographic setting of the North Fork quadrangle differs from that of the Salmon and Baker quadrangles by partaking of the characteristics both of the Basin and Range and of the Northern Rocky Mountain provinces. From south to north the setting changes from mountain ranges separated by broad, intervening basins to broad, deeply-dissected plateau uplands. The Salmon Basin, which separates the Beaverhead and Lemhi Ranges from the Salmon River Mountains in the quadrangles to the south, wedges into the North Fork quadrangle; and as the wedge tapers, the Beaverhead Range begins to lose its range-like characteristics to merge with a somewhat lower group of mountains of the dissected plateau type, which spread westward and northward to become a part of the Salmon River Mountains.

Beaverhead Range

The Beaverhead Range maintains its northwesterly direction until it loses its range-like characteristics near the northern border of the quadrangle. As it enters the quadrangle from the southeast, its scarp-like front rises boldly above the hilly floor of the Salmon Basin (pl. 2 B) until, near the central part of the quadrangle, the rising floor of the basin reduces the relief and prominence of the frontal slope (pl. 3 A). The crest of the range, above 9,000 feet, reaches a maximum of 9,841 feet in Sheep Mountain at the very end of the range. From Sheep Mountain the crest crops abruptly to less than 8,000 feet, where, extending onward, the range loses its identity among lower-level ridges of the dissected plateau type (pl. 3 B). The North Fork of Sheep Creek serves to mark the north boundary of the Beaverhead
Range; and Stein Mountain at 8,535 feet marks the end of the steep frontal slope of the range.

The Beaverhead Range rises several thousand feet above its surroundings and as much as 6,275 feet above the lowest part of the quadrangle at North Fork. Because of its high relief, the upper parts of the range have been deeply sculptured by glacial erosion (pl. 4 A), with the main streams heading in large cirques tucked under the higher ridges and flowing some distance through broad U-shaped valleys before entering narrow canyons in their lower courses.

**Salmon River Mountains**

The North Fork quadrangle covers part of the eastern slope of the Salmon River Mountains, a steep frontal slope that extends southward far into the Salmon quadrangle. The quadrangle boundary crosses the top of the frontal slope for a short distance, but otherwise lies just below the crest. To the west, the dissected uplands that characterize the Salmon River Mountains stretch on for many miles.

The eastern slope of the mountains, rising steeply from the Salmon River, reaches a maximum of 7,835 feet within the quadrangle. Incised by deep, narrow valleys separated by sharp, narrow ridges, the slope shows no evidence of glacial sculpture, except at the head of Wallace Creek just outside the quadrangle.

Although the Salmon River Mountain mass appears to be bordered by the Salmon River, the same type of mountainous topography continues on the east side of the river around the end of the Salmon Basin to the north end of the Beaverhead Range. As far as I know, the intervening mountain mass is unnamed but could well be included within the Salmon River Mountain group.

**Salmon Basin**

The Salmon Basin, the most impressive feature in the Salmon quadrangle (Anderson, 1956, p. 10), wedges into the southern part of the North Fork quadrangle, with its boundary against the Salmon River Mountains extending in a northerly direction, and against the Beaverheads in a northwesterly direction. Except for the relatively flat land bordering the Salmon River and Carmen Creek (pl. 2 B), the basin maintains its low, hilly character to Badger Spring Gulch, where the floor with its hills begins a rise to higher levels (pl. 3 A). The basin aspect ends completely at Silverlead Creek as the mountains come together. The border of the basin coincides essentially with the boundary of the Tertiary volcanic and sedimentary formations.

**Drainage**

The Salmon River, controlling the drainage of all but the Montana section of the quadrangle, flows northward along the west
A. NORTH RIM OF THE SALMON BASIN

The rising floor of the basin reduces the relief and prominence of the frontal slope of the Beaverhead Range. The high hills of the basin rim are composed of Challis volcanics, in places capped by beds of the Geertson formation. The basin beds are crossed locally by Fourth of July Creek. Picture taken from the Salmon River Mountain slope.

B. DISSECTED UPLANDS NORTH OF THE BEAVERHEAD RANGE

The higher-rising slope at the extreme right of the picture marks the end of the Beaverhead Range and the beginning of the lower-level ridges of the dissected-plateau type. The local drainage is Sheep Creek and its tributaries. Picture taken from Stein Mountain.
side of the Salmon Basin and then out of the basin, through deeply entrenched meanders, to North Fork (Pl. 1) where it begins its westerly course across the State. At North Fork it is joined by its largest tributary within the quadrangle, the North Fork of the Salmon River, which flows directly south in a singularly straight course almost along the west boundary of the quadrangle.

In general, the area has many permanent streams, except in the basin where the Tertiary formations tend to favor the development of an intermittent drainage. The principal streams that drain the Beaverhead Range, listed from north to south, are Sheep, Big and Little Silverlead, Wagonhammer, Fourth of July, Boyle, and Carmen creeks. The short streams dissecting the Salmon River Mountain slope carry much less water than the streams from the Beaverheads. The significant streams west of the Salmon River, also listed from north to south, are Comet, Bird, Diamond, and Wallace creeks.

CLIMATE

The climate of the North Fork quadrangle is determined primarily by altitude which, because of the marked difference in area relief, varies considerably from valley floors to high mountain ridges. In the lower country the climate is semiarid, though in general less so than in the basin area in the adjoining Salmon quadrangle. With increasing altitude the climate changes through humid-continental to subarctic. Thus the lower country enjoys somewhat warmer winter temperatures, with considerably less snow, than the higher mountains. The snow comes much later than in the mountains, rarely accumulating in significant amounts until December, and seldom builds up to depths of more than a foot or two. It disappears by early spring. In the higher mountains, on the other hand, snow may appear in early autumn, accumulate to depths of some feet, and remain on the ground until late spring, some drifts on the high divides surviving through the cool short summer. In summer, the normally dry season, there may be some years, a month or two without any precipitation. Generally however, the dry season is interrupted by afternoon thunderstorms of short duration that may bring local copious rains and even cloud-bursts.

The whole area experiences a considerable daily and annual range of temperature, the daily range approaching 30°, especially during cloudless days and nights. Except for temperature inversions, the lower valleys are always considerably warmer, both winter and summer, than the mountains. During the winter the low country may have occasional spells of zero or subzero weather; but the temperatures are more generally in the 20's, ranging upward from the upper teems at night into the 30's and 40's during the day. During the summer the temperatures may rise into the 90's for several weeks, even to or above 100° for a few days at a time, but evenings are invariably cool throughout the hottest weather, the temperatures dropping to the 50's and below at
night. In the higher mountains, winter temperatures may drop and remain below zero for some weeks at a time; but during the summer, when the lower valleys are plagued by heat, the mountains remain pleasantly cool during the day and may become chilly at night.

VEGETATION

The type and distribution of vegetation in the area are largely controlled by climate (altitude) and character of the underlying bedrock or subsoil. Sagebrush and grasses are characteristic of the semiarid lower country (pls. 2, 3, and 4), especially in areas underlain by Tertiary sedimentary and volcanic rocks. The higher country, on the other hand, is more or less continuously forested, except where slopes are too steep and rocky to support tree growth or where lower slopes, facing south, lose moisture too rapidly to sustain a tree growth (pls. 5, 4, and 8).

The forest cover is made up largely of small- to medium-sized evergreens, rising above a surface thickly grown with grasses and shrubs, including sagebrush. The evergreens are mainly Yellow pine, Douglas fir, Engelmann spruce, and lodgepole pine, the distribution of each depending chiefly on altitude and moisture. The Yellow pine favors the lower, forested country; the lodgepole pine and others, the higher slopes.

POPULATION AND INDUSTRIES

The North Fork quadrangle is not heavily populated. It probably has fewer than 800 people, all of whom live in the lower valleys, particularly along the Salmon and North Fork rivers and along the lower reaches of Carmen, Boyle, and Fourth of July creeks. North Fork (pl. 2 A), the only settlement, has a post office, two stores and gas stations, and two motels catering largely to the tourist trade. The small settlement of Carmen is just off the south boundary of the quadrangle. The North Fork Ranger Station on the North Fork of the Salmon River about seven miles above the settlement of North Fork, has a summer population of about two dozen people.

Much of the quadrangle may be regarded as range land with cattle raising the most important occupation. The grass in the valleys and on bordering mountain slopes supports a considerable cattle population during the summer months; hay, the main agricultural crop, raised under irrigation in the bottomlands and on some of the bordering terraces, carries the livestock through the winter.

Although the quadrangle is extensively forested (much of it lies within the Salmon National Forest), logging is a minor industry. A small saw mill is located at North Fork, but most of the logging is carried on outside the borders of the quadrangle.
Mining in the area today can hardly be considered an industry. Some prospecting is carried on annually, but the industry was far more important in the past. There has been no recorded production of consequence for some years.

ACCESSIBILITY

The North Fork quadrangle is easily accessible from Salmon, the county seat of Lemhi County, and from Missoula, Montana, by U. S. Highway No. 93, which extends the full length of the quadrangle (pl. 1). This excellent highway borders the Salmon River from Salmon to North Fork and then continues up the North Fork River to and beyond Gibbonsville.

The highway makes easily accessible the few roads which extend back into the mountains. The Stormy Peak road, graded but otherwise little improved, leaves the highway about two miles south of the quadrangle (some three miles north of Salmon) and crosses the southwest corner of the quadrangle, continuing on to Moose Creek. This road provides the only approach to the upper Salmon River Mountain slope. An unimproved road leaves this road at the crest of the slope and extends north along the ridge to Napoleon Hill.

East of Highway No. 93, only one road extends far back into the Beaverhead Range; the road up Fourth of July Creek, which terminates at the lookout on Stein Mountain. Roads up Boyle and Carmen creeks, which serve the ranchers along those streams, end or become impassable, except along Carmen Creek, at the base of the main mountain slope. Along Carmen Creek the road is a modern, paved highway to the mouth of Freeman Creek, but is little improved from there on. Short roads also extend up Wagonhammer and Kriley creeks.
STRATIGRAPHIC GEOLOGY

FOREWORD

The North Fork quadrangle makes some further contributions to the stratigraphic geology of the Salmon region. In addition to the various bedded sedimentary and volcanic formations and surficial deposits found and described in the Baker quadrangle (Anderson, 1937, p. 13-33), the North Fork quadrangle has a recently recognized Tertiary formation, perhaps equivalent to the early Tertiary conglomerate in the Leesburg quadrangle (Shockey, 1957, p. 11). It also has some intrusive stocks, one of which extends into and has been described in the Salmon quadrangle (Anderson, 1956, p. 39-41). As in the other quadrangles, the Precambrian Belt rocks are restricted largely to the mountainous terrains; and because the North Fork quadrangle is more mountainous than any of the others, except the Leesburg, it has a much greater distribution of these older rocks. Except for the Challis Volcanics, the Tertiary rocks, which include four sedimentary formations, are confined within the limits of the Salmon Basin. The different stratigraphic units present in the quadrangle are named and tabulated chronologically in the following table.

Stratigraphy of the North Fork Quadrangle

| Thickness |
|-----------|-----------------|
| (feet)    |                 |

Quaternary

*Recent*

<table>
<thead>
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<th>Formation</th>
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</thead>
<tbody>
<tr>
<td>Alluvium</td>
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</tr>
<tr>
<td>Pleistocene</td>
<td></td>
</tr>
<tr>
<td>Terrace deposits</td>
<td>10-200+</td>
</tr>
<tr>
<td>Young glacial deposits</td>
<td>0-100</td>
</tr>
<tr>
<td>Old glacial deposits</td>
<td>0-50+</td>
</tr>
</tbody>
</table>

*Unconformity*

Tertiary

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<tbody>
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<td></td>
</tr>
<tr>
<td>Kirtly Formation</td>
<td>300+</td>
</tr>
<tr>
<td>Late Oligocene or early Miocene</td>
<td>800+</td>
</tr>
<tr>
<td>Geertson Formation</td>
<td>500+</td>
</tr>
<tr>
<td>Kenney Formation</td>
<td></td>
</tr>
<tr>
<td>Oligocene(?)</td>
<td></td>
</tr>
<tr>
<td>Challis Volcanics</td>
<td>0-800+</td>
</tr>
<tr>
<td>Eocene(?)</td>
<td></td>
</tr>
<tr>
<td>Kriley Formation</td>
<td>600+</td>
</tr>
</tbody>
</table>

*Unconformity*

*Precambrian*

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</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Swauger Quartzite</td>
<td>10,000+</td>
</tr>
<tr>
<td>Leahi Quartzite</td>
<td>8,000+</td>
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</tbody>
</table>
PRECAMBRIAN BELT SERIES

Subdivision

The Precambrian Belt Series, which consists of a great thickness of dominantly quartzitic beds, is locally divisible into two major units; one of largely impure, generally dark-gray quartzite; the other of quite pure, light-gray quartzite. These two units also differ in grain size and in mineralogic and textural details that reflect quite different environmental conditions during sedimentation. The dark-gray unit was the first to be deposited and is overlain conformably by the light-gray unit, which in its lower part contains beds of distinctive reddish and purplish coloring. The aggregate unit is many thousands of feet thick.

The lower unit appears to be the equivalent of the impure quartzite described by Ross in the Borah Peak quadrangle. Because of its wide extent through the northern part of the Lemhi Range, he has named the unit the Lemhi Quartzite (Ross, 1947, p. 1096). Reappearing across the Lemhi Valley in the Beaverhead Range, the same quartzite may be traced along the Beaverhead Range into and across the North Fork quadrangle into the Salmon River Mountains. The upper unit corresponds to Ross' Swauger Quartzite which he found above the Lemhi Quartzite in the Borah Peak quadrangle (Ross, 1947, p. 1096). The two names proposed by Ross have been accepted for the two corresponding units in the North Fork quadrangle.

Lemhi Quartzite

Within the North Fork quadrangle the Lemhi Quartzite is exposed over much of the Salmon River Mountain slope and northward across the Salmon River to the base of the Beaverhead Range (pl. 1). Appearing also along the lower flank of the Beaverhead Range in the southeast part of the quadrangle, it continues southeastward along the front of the Range through and for some miles beyond the Baker quadrangle (Anderson, 1957, p. 13-14). This same impure quartzite extends across much of the Leesburg quadrangle (Shockey, 1957, p. 7-9) as well as across the northern end of the Lemhi Range in the Salmon quadrangle (Anderson, 1958, p. 16-17).

Locally, the Lemhi Quartzite is a rather monotonous succession of generally thin-bedded, moderately dark-gray, impure quartzite with some intercalations of lighter- and darker-colored beds and of phyllite, and exceptionally, of nearly pure quartzite. Characteristically fine-grained and finely micaceous, the rock generally displays a more or less conspicuous cleavage. Because the quartzite shows transition to phyllite in places, much of the rock along the front of the Beaverhead Range may be aptly described as a phyllitic quartzite. Weathering to a dark, commonly rusty color, the quartzite formation may generally be recognized from afar by the dark, somber appearance of its outcrop.
All the rock shows incipient to fairly well-developed schistosity, which has not interfered, however, with the preservation of crossbedded structures, ripple marks, and bedding planes. The rock is completely recrystallized; but the quartz and other minerals apparently retain their original grain size, the quartz averaging about 0.10 mm. in maximum diameter but reaching 0.5 mm. in some beds. The fineness of grain suggests that the original rock was impure siltstone and fine-grained sandstone.

Under the microscope the impure quartzite reveals considerable but variable amounts of albite, biotite, muscovite, and sericite and a little accessory zircon, apatite, tourmaline, and magnetite. A typical, moderately dark-gray specimen collected in lower O’Neill Gulch between Fourth of July and Wagonhammer creeks revealed under microscopic examination about 50 percent quartz, 30 percent albite, 12 percent biotite, and 8 percent sericite and muscovite along with a few widely scattered grains of zircon, magnetite, and tourmaline. This rock corresponds closely to the typical, impure gray quartzite described by Shockey in the Leesburg quadrangle, where the rock contains 55 percent quartz, 20 percent albite, 10 percent muscovite and sericite, 10 percent biotite, and accessory minerals apatite, zircon, epidote and iron (Shockey, 1957, p. 8).

Representing the darkest of the quartzite in the formation, a specimen of the dark-gray, faintly-banded quartzite collected from the highway cut at the edge of North Fork revealed on microscopic examination about 45 percent quartz, 20 percent biotite, 25 percent albite, and about 10 percent sericite and muscovite, with a meager scattering of zircon and magnetite grains. In the southeast part of the quadrangle, MacKenzie (1949) described the phyllitic quartzite in the Beaverhead Range as 25 to 50 percent quartz, 5 to 25 percent orthoclase (untwinned albite(?)), 5 to 25 percent sericite, 5 to 10 percent chlorite, 2 to 10 percent magnetite and ilmenite, 2 to 5 percent albite, with minor amounts of greenish biotite, muscovite, leucozine, zoisite, and other minerals. In the north end of the Lemhi Range the quartzitic rock is dark greenish, containing much chlorite in addition to biotite (Anderson, 1956, p. 18).

In the Borah Peak quadrangle, the Lemhi Quartzite is principally grayish-green, impure quartzite with subordinate argillaceous beds (Ross, 1947, p. 1096). Some of the beds in the formation are tinted in reddish to purplish tones with lenses of nearly-pure-white to pinkish quartzite here and there in otherwise green quartzite. The beds of greenish quartzite are reportedly about 90 percent quartz and 10 percent plagioclase, with minor amounts of sericite, chlorite, epidote, and locally, green biotite and dark tourmaline. Differences between the rock in the Borah Peak quadrangle and the North Fork region appear to be largely in degree of metamorphism and proportions of impurities. In the Borah Peak quadrangle, the rock shows the beginning of low-grade metamorphism, represented by the greenstone facies in which chlorite is the diagnostic facies mineral. In the North Fork
region, the rock, though still of greenstone facies, represents a more advanced stage characterized by rather extensive development of biotite and albite.

The base of the Lemhi Quartzite is not exposed within the quadrangle, but the top may be observed on the high slope east of the North Fork of the Salmon River, some three to five miles upstream from North Fork (pl. 1). The phyllitic quartzite that forms the upper part of the formation shows rather abrupt gradation into the more coarsely-grained, pale-reddish or purplish quartzite which composes the lower part of the conformably overlying Swauger Quartzite. The thickness of the Lemhi Quartzite cannot be estimated accurately. Though incomplete, the local section has apparently been duplicated by faulting and in places, by close folding. In the Leesburg quadrangle, where both the top and bottom of the formation have been observed, Shockey (1957, p. 9) estimates that the impure gray quartzite is approximately 25,000 feet thick. With allowance for some duplication by faulting, the exposed section in the North Fork quadrangle is probably near 8,000 feet thick.

**Swauger Quartzite**

Composing most of the rock of the Beaverhead Range (pl. 1), the Swauger Quartzite is exposed over nearly half of the North Fork quadrangle. The boundary between the Swauger Quartzite and the other formations extends diagonally across the mid-part of the quadrangle in a northwesterly direction, conforming more or less closely to the base of the Beaverhead Range. Except locally from Big Silverlead Creek to Hughes Creek, it is separated from the Lemhi Quartzite by faults. The basal part of the formation is separated from the main body by a major fault (pl. 1). To emphasize structural relationships, the basal part of the formation—a thin wedge-shaped exposure stretching southeastward along the border of the Beaverhead Range from the North Fork of the Salmon River to Fourth of July Creek—is mapped separately (pl. 1).

The Swauger Quartzite is the most widespread formation in the northern part of the Beaverhead Range. It extends some distance east of the Continental Divide (MacKenzie, 1949) and southeastward along the east margin of the Baker quadrangle. It may also be exposed on some of the lower slopes of the Beaverhead Range in the southeastern part of the Baker quadrangle (Anderson, 1957, p. 15). The purplish quartzite and red slate mentioned by Shockey (1947, p. 9) at the top of the impure gray quartzite formation (Lemhi Quartzite) in the Leesburg quadrangle, could be a remnant of the basal part of the Swauger. Though it has not been observed in the northern part of the Lemhi Range, the Swauger Quartzite is reported to extend eastward beyond the limits of the Borah Peak quadrangle (Ross, 1947, p. 1097).

The light color of the Swauger Quartzite is one of its most distinctive characteristics. Outcrops may be recognized from afar by the generally white appearance of the weathered rock; and where the rock is not exposed, the presence of the formation may usually
be inferred from the light color of the soil. Most of the rock appears to be a rather pure quartzite which varies from white to light gray and pale greenish-gray, except in the lower part of the formation where the rock has a reddish or purplish tint. All the rock, except that reddish or purplish tinted, tends to lighten on exposure; even the tinted rock appears light colored compared to the underlying grayish beds of Lemhi Quartzite.

The quartzite has other distinctive characteristics. Most of it is much more coarsely grained than the Lemhi Quartzite, with grains generally twice as large, in places approaching a coarse grit (MacKenzie, 1949). The grains are not everywhere as firmly bound together as in the Lemhi Quartzite; in fact, some of the rock, which is more like sandstone than quartzite, may weather locally by granular disintegration. Except in cirques and in over-steepened canyon walls, the rock breaks down to form smooth slopes. Good outcrops are otherwise rare, especially along the complex zone of faulting near the margin of the Beaverhead Range (pl. 1).

The quartzite, distinctly layered in beds 6 to 12 inches thick, shows widespread and abundant crossbedding and in places, ripple marks. The rock generally contains detrital grains of feldspar; some of the rock is quite arkosic, exceptionally with almost as much feldspar as quartz. The quartzite also contains up to 5 percent iron ores, chiefly magnetite, but is generally lacking in ferromagnesian minerals, containing exceptionally little accessory biotite. Apparently less metamorphosed than the Lemhi Quartzite, the rock contains virtually no chlorite or biotite and generally only minor amounts of albite. Muscovite and sericite are relatively abundant. The rock is rarely schistose, possibly because much of it is somewhat more competent than the Lemhi Quartzite.

The reddish-tinted rock in the lower part of the formation is highly arkosic, resembling in the hand specimen sandstone rather than quartzite. Grains are of medium size with small grains of muscovite conspicuously distributed along bedding planes. Under the microscope these rocks have from 50 to 65 percent quartz, 25 to 45 percent feldspar (mostly clastic grains of altered plagioclase and less abundant grains of microcline), 3 to 15 percent sericite and muscovite, up to 5 percent magnetite and hematite, and widely scattered grains of zircon, tourmaline, and biotite. Mostly angular, the grains of quartz and feldspar are appreciably larger than the quartz and albite grains in the underlying Lemhi Quartzite.

The light-colored quartzite that characterizes the larger part of the formation shows minor variations in composition and texture. Nearly white, the sandstone-like rock on the high ridge west of Carmen Creek is composed of about 15 percent albite and microcline, 10 percent muscovite, and about 75 percent quartz with accessory zircon, magnetite, and zoisite. Some of the feldspar grains, clearly detrital, originally derived from granite. East
of Carmen Creek, MacKenzie (1949) has found beds of quartzite with numerous quartz and granite pebbles measuring up to 2 inches in diameter. His microscopic studies reveal that the quartzite along and east of the Continental Divide has 50 to 70 percent quartz, 5 to 10 percent feldspar, 5 to 15 percent muscovite, 10 to 15 percent sericite, and 2 to 5 percent magnetite.

Random specimens collected elsewhere in the North Fork quadrangle show only minor variations in mineral proportions and only slight differences in grain size or texture. One specimen from a faintly banded rock bordering the West Fork of Boyle Creek is composed of about 60 percent quartz, 30 percent albite and microcline, 5 to 10 percent muscovite and sericite, 3 percent magnetite, with a little accessory zircon. Some float along the same creek contains about 75 percent quartz, 10 percent muscovite, 5 percent microcline, 5 percent albite, 2 percent magnetite, with a little accessory biotite and zircon. Some of the perthitic microcline occurs as rather large detrital grains. A specimen from a bed of light-gray, ripple-marked quartzite from the cirque wall at the head of the South Fork of Sheep Creek, contains from 25 to 35 percent sericite and muscovite, no feldspar, acnnt grains of magnetite, and 70 to 75 percent quartz. Another specimen, collected elsewhere in the quadrangle as representative of the light-gray quartzite, reveals 45 to 50 percent quartz, 30 percent albite, 10 percent muscovite, 5 percent magnetite, 2 percent biotite, and accessory zircon, tourmaline, zoisite, and apatite.

Except in its lower part, the Swauger Quartzite does not appear to have the purplish and reddish coloring that distinguishes so much of the rock in the Borah Peak quadrangle (Ross, 1947, p. 1097-1098). The type Swauger Quartzite otherwise has about the same compositional and textural characteristics as the rock in the North Fork quadrangle. As Ross points out, the color may be a most unreliable guide in studying stratigraphic relations of the quartzite in the general region. Many of the beds in the type locality contain feldspar; in fact, in some of the beds the feldspar forms more than 10 percent of the rock. Most of the feldspar is sodic plagioclase, but some is microcline, both commonly smaller and less perfectly rounded than the quartz grains. Much of the rock also contains scattered grains of quartzite (Ross, 1947, p. 1097-1098). Appearing to be somewhat more heterogeneous in its makeup than in the North Fork region, the formation shows much interfingering of argillaceous beds and lenses which vary in color and composition along the strike. In the North Fork region the formation appears to be less contaminated by argillaceous materials and more like the Hoodoo quartzite in the Yellowjacket district of western Lemhi County (Ross, 1934, p. 18-19).

The thickness of the Swauger Quartzite is not precisely known. The top of the formation was not observed and faulting has added to the difficulties of estimating thicknesses. As much as 5,000 feet of vertically-dipping, reddish-tinted quartzite lie above the Lemhi Quartzite on the high ridge east of the
North Fork of the Salmon River. The light-gray quartzite extending eastward across the Beaverhead Range must be at least twice as thick, possibly more. Probably more than 15,000 feet of Swauger beds are exposed in the North Fork quadrangle.

TERTIARY STRATIFIED ROCKS

Foreword

The Tertiary stratified rocks are represented by five unconformable formations: the Challis Volcanics, the three overlying sedimentary formations recognized in the Baker quadrangle, and a new, previously unrecognized sedimentary formation beneath the Challis Volcanics. Probably Eocene or somewhat earlier, this new formation is named the Kriley Formation from its position near Kriley Creek. The other formations are the Kenney, Geertson, and the Kirtley (formerly the Carmen). Because Carmen is used elsewhere as a formational name, its use had to be discontinued and a new name substituted.

All the sedimentary formations are restricted to the Salmon Basin, a structural basin which apparently came into existence during the early part of the Tertiary. The Challis Volcanics, not thus restricted, extend far beyond the limits of the basin.

Kriley Formation

The best and perhaps the only exposures of the newly recognized Kriley Formation are along the east side of the Salmon River, both north and south of Boyle Creek. The exposure north of Boyle Creek extends nearly to Kriley Creek (pl. 1). Skirting the highway, both exposures are partly visible in the lower canyon wall (plis. 4 A and 7 B). Two small exposures of possible Kriley Formation have been mapped west of the Salmon River near the south boundary of the quadrangle (pl. 1).

The Kriley Formation is chiefly a thick conglomerate, topped near Kriley Creek by a succession of more finely-textured clastic beds. The lower part, a thick, basal conglomerate, is visible from the highway as cliff-like exposures in the canyon wall. Near Kriley Creek the cliff exposure is more than 100 feet high facing the river (pl. 7 B). The coarsely textured conglomerate is composed of boulders up to a foot in diameter, firmly held in a cemented, silty and sandy matrix (pl. 5 A). Generally well water-worn, the boulders have been derived largely from the Lemhi Quartzite with some admixture of granitic rocks. Near Kriley Creek the thick, massive bed of conglomerate is overlain by light-colored, well-stratified beds of sandy shale and sandstone which, except in the cliffed exposure facing the river, have poor outcrops. South of Boyle Creek the conglomerate is even thicker, showing better-developed bedding above the lower few tens of feet. Well-cemented, it is composed largely of materials from the Lemhi Quartzite with some admixture of granitic
rock from the Idaho batholith. The conglomerate here is made up mostly of boulders ranging up to 6 inches in diameter. There are more than 800 feet of beds in the extensive exposure south of Boyle Creek (pl. 4 B).

Resting unconformably on the Lemhi Quartzite, the conglomerate near Kriley Creek appears to occupy an old valley carved in the Precambrian rocks (pl. 7 B). The formation there passes unconformably under a cover of Challis and Geertson beds. South of Boyle Creek the volcanics are missing and the conglomerate disappears directly beneath the Geertson Formation (pl. 4 B).

With no fossils to date the formation, it is known only that the Kriley is younger than granitic rocks derived from the Idaho batholith and older than the local rocks regarded as belonging to the Challis Volcanics. Shockey (1957, p. 11) has found a coarse conglomerate as much as 100 feet thick near the eastern edge of the Leesburg quadrangle on Williams Creek, nearly 20 miles to the south of the Boyle Creek exposures. Composed of quartzy and granitic pebbles, cobbles, and boulders up to several feet in diameter, the conglomerate there is also overlain unconformably by the Challis Volcanics. Shockey notes the similarity between this conglomerate and those described by Scholten and others (1955) over a broad region in southwestern Montana; he considers their origins the same: either the conglomerates were deposited in response to Laramide uplifts in early Tertiary (Paleocene) time, or they were deposited with somewhat younger, post-Laramide Eocene conglomerates. The Kriley Formation may be similarly correlated, but whether it is the equivalent of the Beaverhead conglomerate of Paleocene age or one of the younger Eocene conglomerates in the Lima region (Scholten and others, 1955, p. 368-369) cannot be definitely established at this time. That it rests on the surface of beds previously folded, but is itself somewhat folded with the same general trend as the later Laramide folds, suggests possible correlation with the Beaverhead conglomerate.

Challis Volcanics

The Challis Volcanics, a name applied by Ross (1934, p. 46) originally to a thick and diverse assemblage of Tertiary volcanic rocks in the Challis region, are exposed in the northwestern part of the quadrangle, mainly in a narrow, tapering band that emerges from beneath a cover of Geertson beds in the vicinity of Kriley Creek and extends northwestward to the valley of Little Silver-lead Creek (pl. 1). Isolated patches are scattered throughout the valley of the North Fork of the Salmon River; another larger patch occurs above the junction of Hughes Creek in the northwest corner of the quadrangle. Several other patches lie on both sides of the Salmon River, the larger ones more or less directly across from the mouths of Fourth of July and Wagonhammer creeks on the southwest side of the river (pl. 1). These patches are remnants of a former extensive cover that buried a surface as deeply, and in part, as sharply dissected as that of today. The main band of volcanics apparently accumulated in an ancient, rather broad
A. GLACIALLY SCULPTURED BEAVERHEAD RANGE
Picture shows the rugged, ice-sculptured slopes of the higher parts of the Beaverhead Range drained by Fourth of July Creek. The light color of the Swauger quartzite gives the rocky terrain its light appearance.

B. KRILEY FORMATION
Thick, gently-folded conglomerate beds of the Kriley formation (K), passing unconformably under nearly flat beds of the Geertson formation (G).
valley that opened into the ancestral Salmon Basin; whereas the isolated masses represent remnant fillings in former, generally steep-walled, tributary valleys.

The Challis Volcanics consist of flows and pyroclastics, the latter composing the larger part of the exposed rock. The intercalated flows have a sporadic distribution, but appear to be more prevalent in the lower than in the upper parts of the formation. Individual flows are generally limited in extent, partly because of interruption and disappearance by faulting. The flows and bedded pyroclastics are generally tilted and rather deeply eroded. Perhaps as much as 500 feet of the formation remain in some of the larger exposures.

The volcanics show some variety in rock types. The flows are represented by andesite, dacite, and rhyolite. Because only a few flows were selected for petrographic study, there remains the possibility that other rock types may exist. The pyroclastics include both bedded tuffs and lava-like flows of ignimbrites (welded tuffs).

**Andesite**

A thick flow of hornblende-biotite andesite with bold, dark outcrop extends across the lower valley of Kriley Creek near the western edge of the main band of volcanics. It is underlain and overlain by tuffaceous beds.

Beneath the dark, weathered, generally rusty surface, the somewhat vesicular rock is light gray and conspicuously porphyritic with abundant dull feldspar phenocrysts less than 2 mm. long. These form about 20 percent of the rock and along with a few hornblende and biotite crystals are set in a dense grayish groundmass. The microscope reveals that the feldspar phenocrysts are composed of calcic andesine and that the hornblende is a brownish, much-altered basaltic variety. The phenocrysts are enclosed in a brownish-gray, glassy groundmass with a sprinkling of tiny feldspar microlites. The microscope also shows the presence of tiny, scattered crystals of magnetite and zircon. Tridymite occurs as a partial filling of some of the vesicular openings.

**Dacite**

Dacite flows appear to be quite extensively developed along the western edge of the main volcanic belt, particularly in the vicinity of Wagonhammer Creek and Burns Gulch, and along the river south of Fourth of July Creek. The rock appears to form a thick, basal flow which occupied or filled one of the old Tertiary valleys.

Where not dulled and darkened by weathering, the dacite is light gray, conspicuously porphyritic with an abundance of dull, chalky feldspar phenocrysts up to 0.5 inch long and with much lesser amounts of quartz and altered biotite. The quartz forms
strikingly visible grains up to 0.3 inch long. The feldspar phenocrysts compose about 25 percent of the rock, the quartz up to 10 percent, and the biotite less than 5 percent. These phenocrysts are contained in faintly greenish-gray, fine-grained groundmasses which cannot be resolved by the unaided eye. The microscope reveals that the rocks are highly altered and that the groundmasses, though greatly decomposed, are microgranular, composed largely of a silicic plagioclase with a minor amount of quartz and apparently of orthoclase. Although much altered, the plagioclase phenocrysts had originally an intermediate composition. The large quartz phenocrysts show extensive resorption phenomena with rounding and embayments. The decomposition products of the feldspar and ferromagnesian minerals include sericite, chlorite, and calcite. Magnetite is fairly abundant in the rock.

Rhyolite

Some of the rock across from the North Fork Ranger Station in the northwest corner of the quadrangle (pl. 1) has a rhyolitic composition and is probably from a flow, although some of the flow-like rock in the area is actually represented by ignimbrite. The flow rhyolite, however, appears to be widespread.

The rhyolite is a light-colored, porphyritic rock with a sprinkling of fresh feldspar and biotite crystals in a pale, brownish-gray groundmass which, the microscope reveals, is composed of microspherulites. Microscopic examination also reveals occasional quartz grains among the scattered andesine phenocrysts.

Tuff

The tuffaceous beds are generally light-colored, but some beds, apparently of a less silicic composition, are appreciably dark. The only specimen collected for microscopic study was from a bed of pebbly tuff along the Salmon River across from the mouth of Boyle Creek. This tuff, with its abundant small pebbles and grains of quartzite and other rock, is light gray and well-consolidated, with much feldspar visible in the matrix. The microscope reveals clastic grains and fragments of feldspar, hornblende, chloritized biotite, quartzite, quartz, and volcanic rock in a glassy matrix in which the glass, composed of glass shards, is partly devitrified.

Ignimbrite

What appears to be a thick, massive, erosionally resistant flow in the small gulch just south of the mouth of Kiley Creek proves to be an ignimbrite (welded tuff). Apparently rather highly porphyritic, the grayish rock contains, in addition to the visible grains of feldspar, quartz, and biotite, abundant inclusions of quartzite and other rocks. The microscope shows that the rock is loaded with quartzite inclusions, with numerous broken grains and crystals of quartz and lesser plagioclase, torn and bent crystals of biotite, and scattered crystals of zircon and
magnetite; all in a glassy groundmass of bent shards and, in places, closely-associated coarse microspherulites. About half of the rock is composed of this glassy material. The rock is firmly welded and difficult to break.

An ignimbrite apparently intercalated with the rhyolite across from the North Fork Ranger Station, is somewhat different from the one near Kriley Creek. It appears to form a thick, massive flow of a grayish glassy-or pitchy-looking porphyritic rock containing numerous small crystals of quartz, feldspar, and biotite. Under the microscope the abundant, broken quartz grains, which occur locally as breccia-like aggregates; the lesser andesine; and the numerous bent and broken biotite crystals are cemented in a groundmass of microspherulites, probably formed by devitrification of original glass. The glass otherwise abounds in crystallites, notably in globulites and trichites. Most of the feldspar and biotite grains are remarkably fresh.

Age

Because no fossils were observed in the tuffaceous beds, direct dating of the volcanics is not possible. On the basis of paleobotanical and other evidence, Ross (1937, p. 65-68) expressed the opinion that the Challis Volcanics are possibly, if not probably, of Oligocene age and hardly younger than early Miocene. The age of the Challis Volcanics is still under study. Whether some of the fossils collected and studied by R. W. Brown should be regarded as of late Oligocene or early Miocene age has not been finally decided. Ross and Forrester (1958, p. 14) think it entirely possible that the lower part of the Challis Volcanics is of Oligocene age though some of the beds high in the sequence may be as young as early Miocene. The dating is further complicated by the fact that a single age determination of zircons from a sample of the granite that intrudes the Challis Volcanics near the Middle Fork of the Salmon River indicates an age of 39 million years, a date which would place the age of the volcanics near the beginning of Tertiary time, much earlier than the fossils suggest (Ross and Forrester, 1958, p. 15).

Kenney Formation

The Kenney Formation, named from Kenney Creek in the Baker quadrangle (Anderson, 1957, p. 15-17), is exposed in several places in the southeastern part of the North Fork quadrangle, where erosion has stripped away the cover of younger formations. The largest exposure is southeast of Carmen Creek (pl. 1) where about 4 square miles of the formation have lost their cover of Geertson and Kirtley beds. Two smaller exposures lie just to the north, one on the east side of Carmen Creek, the other on the west side. That on the west side appears as a window in the valley side beneath a capping of the Geertson Formation.

Much the same as in the Baker quadrangle, the Kenney Formation consists of a thick succession of shales, sandstones, and
conglomerates with local intercalations of tuffaceous materials. The conglomerates, however, may form a considerably larger part of the formation than in the type locality. The exposures bordering Carmen Creek north of the mouth of Freeman Creek are largely conglomerate; those west of Carmen Creek are derived mainly from the Lemhi Quartzite; and those east of the creek, from the Swauger Quartzite. The broad exposure south of Carmen and Freeman creeks (pl. 1) contains a considerable proportion of light-colored, shaly and sandy beds; but thin lenses of conglomerate throughout are the only part of the formation with recognizable outcrops (pl. 5 B).

Because the formation was not measured, its thickness can only be approximated until a full section has been pieced together, perhaps an impossible undertaking, inasmuch as the top has been removed by erosion. More than 500 feet of beds are exposed within the quadrangle.

No fossils were observed anywhere in the formation, which makes precise dating impossible. But its position above the Challis Volcanics and below the Geertson and the Kirtley Formations (middle Miocene or younger) indicates a probable upper Oligocene age.

Geertson Formation

The Geertson Formation, named from Geertson Creek in the Baker quadrangle (Anderson, 1957, p. 17-18), is the most widespread of the Tertiary formations in the North Fork quadrangle. (pl. 1). The main exposure extends continuously as the foothill floor of the basin from Carmen Creek to Kitley Creek, a distance of about 7 miles. From Kitley Creek to Wagonhammer Creek the exposures continue as high ridge cappings on Challis Volcanics and Lemhi Quartzite. One other important exposure blankets part of the Kenney Formation in the southeast corner of the quadrangle (pl. 1).

The formation differs considerably from the Geertson in the type locality. Instead of a thick assemblage of light-colored, shaly beds with some intercalated bentonite, sandy shale, sandstone, and pebble conglomerate (Anderson, 1957, p. 17-18), it is almost entirely conglomerate with minor thin partings of sandy shale. Toward the more southerly part of the quadrangle, however, there is less of the conglomerate and correspondingly more shale. The formation is composed of fairly well-cemented material of alluvial character with the characteristics of an extensive fanglomerate, which grades southeastward into the shaly and pebbly beds typical of the formation in the adjacent quadrangle.

The fanglomerate is composed almost exclusively of rounded to subangular, poorly-sorted gravel and boulders in a cemented matrix of angular pebbles, sand, and silt. Made up largely of materials from the Swauger Quartzite, it is much lighter in color than the conglomerate beds of the locally underlying Kenney and Kitley Formations. Because the fanglomerate generally disintegrates
A. KRILEY CONGLOMERATE
Picture shows bouldery character of the well-consolidated Kriley formation.

B. KENNEY FORMATION
Ledges of northwesterly-dipping beds of conglomerate in the Kenney formation. Picture taken up Carmen Creek with the Beaverhead Range in the background.
A. THE TOWERS
Pedestal rocks formed by differential weathering and erosion of conglomerate beds of the Geertson formation.

B. OLD GLACIAL BOULDERS
Large granite erratics carried down the Salmon River Mountain slope to the Salmon River by a tongue of ice from the ice cap on the Salmon River Mountains during the early part of the Pleistocene.
rather rapidly on exposure to the weather, outcrops are comparatively rare and the surface is generally mantled by a cover of loose gravel with cemented sand still clinging to some surfaces. Under appropriate erosional conditions, the conglomerate produces castellated outcrops and pedestal rocks, features well-developed on the slopes north of Boyle Creek. The pedestal rocks, referred to by the Lewis and Clark party in the early part of the nineteenth century as the "Towers," are capped by large boulders usually above narrow supporting stumps (pl. 6 A).

The thickness of the formation is not fully known. The formation passes unconformably under the Kirtley Formation and spreads unconformably over the eroded surface of the Kriley and Kenney Formations and the Challis Volcanics. As much as 500 feet of beds have probably been exposed by subsequent erosion.

The conglomerate is without fossils but some of the shaly beds in the Baker quadrangle contain plant remains which, when collected and studied, should provide a reliable clue as to the age of the formation. Older than the Kirtley, the formation can be no younger than lower Miocene. The conglomerate may have much in common with the Donkey conglomerate in the Borah Peak quadrangle, which has not been more accurately dated than Tertiary (Ross, 1947, p. 1122-1123).

Kirtley Formation

The Kirtley Formation, renamed from the Carmen because that name was preoccupied, extends only a short distance into the North Fork quadrangle. As originally applied in the Salmon quadrangle, the name Carmen was given to all the Tertiary sedimentary strata within the Salmon Basin (Anderson, 1956, p. 28-30); but when study of the Baker quadrangle was begun, the Tertiary beds were found to contain three unconformable formations, for the youngest of which the name Carmen was retained (Anderson, 1957, p. 15-19). Later, when it was learned that Carmen had been used as a formalional name elsewhere, the name Kirtley was accepted and applied to the youngest of the Tertiary formations throughout the Salmon Basin. The formation takes its name from Kirtley Creek which flows across it near the center of the Salmon quadrangle.

The Kirtley Formation extends less than two miles into the southern part of the North Fork quadrangle, its largest exposure occurring as a tapering, wedge-shaped mass of low hills between lower Carmen Creek and the Salmon River (pl. 1). A smaller exposure lies in the lower foothills west of the river. South of lower Carmen Creek the formation is widespread in the more central part of the Salmon Basin.

Although a little conglomerate occurs at or near the base of the formation, particularly west of the river, the formation as a whole is characteristically without coarse, clastic materials, consisting largely of moderately well-indurated, thin-bedded, fine-grained rocks, which are mostly shales that have some
intercalated sandstone and sandy shale. The shales are distinguished by good stratification and by variable differences in physical and chemical characters. Some of the beds are highly siliceous; many are sandy, especially above and below beds of sandstone. In the adjoining quadrangle the shale in places is darkened by vegetable debris, but otherwise, beds are white or light gray. Bentonitic beds were not observed in the North Fork quadrangle, though they are conspicuous in the formation farther south. Sandstone beds are relatively thin, generally lacking conspicuous outcrops. Where they have been studied in the Salmon quadrangle, these beds are composed of fairly well-cemented quartz grains with a subordinate admixture of feldspar, mica, magnetite, clay, and trivial amounts of several other minerals.

Several hundred feet of the Kirtley beds are exposed in the southern part of the North Fork quadrangle, but the total thickness is probably several times that amount.

R. W. Brown who originally regarded collections of fossils obtained in exposures near Salmon as probably lower Miocene (Anderson, 1956, p. 30-31), now considers them as middle Miocene or younger (Ross and Forrester, 1958, p. 14).

QUATERNARY DEPOSITS

Foreword

Quaternary deposits, well-represented in the North Fork quadrangle, include early and late Pleistocene glacial deposits, somewhat younger terrace gravels, and Recent alluvium. All these deposits, except the younger glacial deposit, are shown on the geologic map (pl. 1). The terrace gravels are not as extensively developed as in the Salmon and, particularly, in the Baker quadrangle.

Older Pleistocene glacial deposits

The older Pleistocene glacial deposits were mentioned but not mapped in the studies of the Salmon and Baker quadrangles; but because they obscure the geologic relations of the older rocks so effectively over considerable areas in the North Fork quadrangle, they could not be omitted from the geologic map (pl. 1). These deposits, which occur some distance below the levels reached by the later Wisconsin glaciers, are found today on the lower slopes of the Salmon River Mountains and on the tops of the hills and ridges bordering the Beaverhead Range, some hundreds of feet above the bottoms of the present stream valleys.

One of the largest exposures is on the low hill between the forks of the Fourth of July Creek at the base of the Beaverhead Range (pl. 1). Capping about one square mile of the hill and ridge tops, these deposits hide completely the underlying Swauger Quartzite and its contained faults. Except where subsequently
eroded, these deposits have a smooth surface that slopes away from the range. The materials exposed on the surface are small, angular blocks of quartzite and angular-to-subangular boulders partly embedded in a silty matrix. The materials are derived entirely from the Swaiger Quartzite. The textural characteristics of the deposits could not be observed, but surface features suggest a till and outwash origin.

Smaller exposures of the old glacial deposits are widespread along the lower flanks of the Salmon River Mountain, from the vicinity of Comet Creek southward into the Salmon quadrangle (pl. 1). The exposures obscure the relations of the Lemhi Quartzite on both sides of lower Bird Creek and effectively conceal areas of the Tertiary sedimentary rocks and Lemhi Quartzite south of Diamond Creek. The deposits cap the ridges and slopes between the present streams, almost to the Salmon River. The materials apparently accumulated on a broad, sloping surface that was subsequently incised for some hundreds of feet by the present drainage.

The deposits contain abundant materials of granitic origin, admixed with rock debris from the Lemhi Quartzite. Large granite boulders, probably weighing up to five tons, rest conspicuously on the surface of the deposits or appear in exposures in upper valley walls. These boulders extend almost to the river (pl. 6 B). Showing little or no evidence of sorting, the deposits appear to be chiefly till. The granite composing the boulders is very coarse-grained and does not match that in the stock higher on the slope. Most of the granite has apparently come from outliers of the Idaho batholith some distance back in the Salmon River Mountains, transported to and deposited at the present site by tongues of ice that spilled from the ice cap that then covered the mountains.

The till is like that described in similar settings in the Salmon (Anderson, 1956, p. 21-22), Baker (Anderson, 1957, p. 19-20), and Leesburg (Shockey, 1957, p. 13-14) quadrangles. These deposits are considerably older than those made by the more recent Wisconsin glaciers that clustered high on the present mountains, enough older to have allowed as much as a thousand feet of canyon cutting before the younger glaciers made their appearance.

Late Pleistocene glacial deposits

The late Pleistocene glacial deposits are confined to the valleys in the higher parts of the mountains; and because these deposits have such limited exposures, they are not shown on the geologic map of the quadrangle. The deposits are strewn along the floors of the glaciated valleys, with greater concentration at the lower ends of the former glaciers where the debris has been heaped into piles of terminal moraine. Such deposits are especially conspicuous along the upper course of Carmen Creek just within the Beaverhead Range as well as along upper Fourth of July Creek and the upper forks of Sheep Creek.
Composed entirely of Swauger Quartzite, the deposits are an unassorted, heterogenous mixture of rock fragments and small to large boulders of different degrees of angularity, representing material carried down largely from the heads of the valleys.

**Pleistocene terrace gravels**

Gravel or alluvial terraces are conspicuous features along some of the streams and at places along the Salmon River, but they are not generally so extensively developed as in the Salmon and Baker quadrangles. The terraces are absent altogether along the North Fork of the Salmon River. In the quadangle, as elsewhere, the terraces occur at three levels, rising boldly above present valley floors; in places, one terrace above the other. They are not continuously exposed, especially along the river, where they have been partly removed by erosion. The terraces are best displayed along Carmen Creek and along parts of Fourth of July Creek (pl. 7 A).

**Upper terrace gravels**

The oldest and highest terrace has the most restricted distribution; but sizable remnants remain along the upper valley slopes bordering Carmen Creek and its tributaries, more or less immediately in front of the Beaverhead Range (pl. 1). Smaller remnants also are left along the north side of Fourth of July Creek where the creek emerges from the main part of the range (pl. 7 A). Several minor remnants are preserved along the main Salmon River. In places, these remnants rise abruptly above the intermediate terrace; but where the intermediate terrace and the one below have been removed by recent erosion, the high terrace remnants rise steeply from the present valley floor.

The terrace remnants are composed of coarse, bouldery gravels derived, except along the river, from rocks of the Beaverhead Range. Along Carmen Creek they are composed of materials from the granite stock and from both the Lemhi and Swauger Quartzites, but along Fourth of July Creek they consist almost exclusively of Swauger Quartzite. The terrace gravels bordering the river have a more varied composition.

The upper terrace gravels may represent outwash deposited by the glacial melt waters during the Wisconsin glaciation; or gravels deposited somewhat earlier, in the interglacial epoch, during a pause in the rejuvenation and dissection of the mountains and valleys.

**Intermediate terrace gravels**

Not as restricted as the upper terrace (pl. 1), the intermediate terrace extends far down-valley along Carmen and Fourth of July creeks and along the Salmon River below the mouth of Carmen Creek. It also appears here and there along the valley of Boyle Creek.
A. PLEISTOCENE TERRACES
Multiple Pleistocene terraces at the mouth of the Fourth of July canyon at the border of the Beaverhead Range. Rocks in the foreground are composed of the Challis volcanics; in the background, of the Swauker quartzite.

B. EROSION SURFACE BENEATH THE KRILEY FORMATION
Basal beds of Kriley conglomerate (K) occupy a rather broad, shallow valley carved in the unconformably underlying beds of Lemhi quartzite. Lighter-colored beds of the formation appear at the top of the exposure. Challis volcanics occupy a much steeper and deeper valley carved across the Kriley formation and Lemhi quartzite at the left of the conglomerate exposure. Dark line of brush at left of highway marks the course of Kriley Creek.
The gravels of this terrace are similar to those of the upper terrace, but down-valley the deposits are less bouldery and otherwise not so coarse. Except west of the Salmon River, they are mostly wash from the Beaverhead Range, probably accumulated as glacial outwash during the younger Wisconsin glaciation. In the terraces along the river the gravel is more varied because of admixture of volcanics and materials from non-local sources.

Lower terrace gravels

The lower terrace, the most extensive, is especially well-developed along Carmen Creek and along parts of Fourth of July Creek and the Salmon River (pl. 1). Along other streams the terrace is too small to show on the map. It extends continuously up Carmen Creek from the river to the base of the Beaverhead Range.

Except along the river, the lowest terrace, like the highest one, is composed of gravels derived chiefly from erosion of rocks of the Beaverhead Range, predominantly the Swauger Quartzite, but locally the Lemhi Quartzite, as well, with minor local admixture of granitic and more resistant volcanic rock. The gravels along the river contain a much higher proportion of Lemhi Quartzite, with some other kinds of rocks from more distant sources.

Recent alluvium

The Recent alluvial deposits covering the valley floors consist of the present floodplain deposits plus such alluvial fan materials as have accumulated along the margins of the floodplains at mouths of tributary gulches. These deposits form strips of variable width along the lower courses of each of the major streams, a few reaching up into the Beaverhead Range (pl. 1). The alluvial strips generally broaden where the streams have carved their valleys in the relatively easily erodable Tertiary volcanic and sedimentary formations (pl. 2 B), narrowing where the valleys are carved in the more resistant Belt rocks. These alluvial strips show to especial advantage along Carmen, Boyle, and Fourth of July creeks, and in places along Wagonhammer Creek.

Where the Salmon River enters the quadrangle and for some distance beyond, the bank of alluvium is broad, more than a mile across (pl. 2 B). About four miles down-valley, however, the alluvial strip narrows and in places disappears almost entirely as the river leaves the Salmon Basin to continue its course through entrenched meanders, deeply cut across the northern flank of the basin and the higher mountains to and beyond North Fork. Along the remarkably straight valley of the North Fork where the alluvial strip is generally less than one-fourth mile wide, it persists with little change upstream far beyond the borders of the quadrangle.

Along the Salmon river the alluvial strip built up of floodplain deposits is composed largely of gravel with some sand and
silt, much of it derived from bordering terraces, with additions from tributary streams. The stream alluvium is also fairly coarse, moderately well-sorted gravel derived from the rocks exposed up-stream and from bordering terraces. Only sand and silt occur in the interstices between the pebbles and cobbles.

INTRUSIVE IGNEOUS ROCKS

General features

The North Fork quadrangle contains a number of intrusive bodies; some occupy a prominent place on the geologic map (pl. 1); others are too small to be shown. The two largest bodies are stocks; the others are dikes and small irregular masses without especially distinctive shapes. The stocks are composed separately of quartz monzonite and granodiorite; but the smaller bodies show a considerable range in composition: gabbro, dacite porphyry, quartz monzonite granophyre, and lamprophyre. Some of the rocks are not entirely magmatic, for the quartz monzonite reveals evidence of replacement origin; and one small body, which may be classed as a replacement porphyry, shows an origin by incipient granitization.

Although the intrusives show an appreciable range in age, they all appear to be younger than Laramide structures; some are certainly younger than the Challis Volcanics. Intrusives may thus be assigned to two principal groups: one more or less closely associated with the Laramide orogeny at the close of Cretaceous time (late Cretaceous–early Tertiary); and the other associated with the intrusive activity in mid-Tertiary time. The earlier intrusives, except for the lamprophyres, are all composed of granular rocks; whereas the mid-Tertiary intrusives are porphyritic, showing two stages of cooling and crystallization.

Late Cretaceous–early Tertiary intrusives

Foreword

Included in the early group of intrusive rocks are the bodies of metagabbro, granodiorite, quartz monzonite, and possibly the lamprophyres. Each member differs somewhat from the others, sufficiently so to suggest no immediate magmatic ties. Because of its more extensive alteration, the gabbro is thought to be the earliest of the intrusives. Nothing in the field relationships indicates the order of emplacement of the two quite dissimilar bodies of granodiorite and quartz monzonite; but, because of the more alkalic nature of the quartz monzonite, it is presumed to represent a more advanced magmatic product and is hence probably younger than the granodiorite.

Metagabbro

The metagabbro is exposed at the base of the Beaverhead Range in the southeastern corner of the quadrangle just across
from the Dike mine (pl. 1). It appears to be in a down-faulted segment of Lemhi Quartzite; but because of a cover of Tertiary and Quaternary rocks, its relations are not clearly defined. No more than a few hundred feet of the poorly exposed body are visible along the gulch bottom.

The metabasalt is much like that exposed near the summit of the Beaverhead Range (Anderson, 1957, p. 24-25). Distinctive in appearance, it is characterized by a dull, greenish-gray to greenish-black color, by uniform granularity of medium-sized, poorly-defined grains, and by evident effects of extensive alteration largely unrelated to weathering.

Originally, the rock was composed largely of hornblende, augite, and calcic plagioclase, with subordinate biotite, a little orthoclase and quartz, and accessory apatite, zircon, and magnetite. Now the rock consists largely of secondary products, particularly uralitic amphibole, chlorite, zoisite, sericite, albite, and calcite. Thus altered, the original minerals can hardly be distinguished. The augite that remains occurs mainly as remnant inclusions in grains of hornblende or as chloritic and uralitic pseudomorphs. Originally it may have been more abundant than the hornblende. Most of the hornblende which has been converted to the uralitic variety and to chlorite, may be recognized chiefly from crystal outline. The uralitic hornblende not only replaces augite and the primary hornblende but also penetrates into the plagioclase, which is otherwise more or less completely saussuritized (converted to fine aggregates of zoisite, sericite, epidote, and albite, with destruction of twinning lines). The plagioclase is presumed to have had the composition of sodic labradorite. The small amount of orthoclase occurs as micrographic intergrowths with quartz, apparently the end product of crystal fractionation.

The age of the gabbro cannot be fixed precisely until time measurements are made of the radioactive accessory minerals. Along the crest of the range, similar rock is intruded along the zone of one of the prominent high-angle thrust faults; and because the thrusting was regarded as a Nevadan structure, the conclusion was drawn that the gabbro had been intruded during later stages of the Nevadan orogeny, that is, during late Jurassic time (Anderson, 1957, p. 25). Structural studies made since in the North Fork quadrangle indicate that the folding and faulting are probably Laramide rather than Nevadan and that the gabbro must have been intruded at the close of Cretaceous rather than Jurassic time. The gabbro may possibly represent the earliest injected magma; its early intrusion may explain its extensive alteration by emanation associated with later magmatic activities.

**Granodiorite**

Restricted to the Beaverhead Range, the granodiorite is the prevailing rock of a small stock and outlier near and along Carmen Creek in the southeast part of the quadrangle (pl. 1). The stock, somewhat irregular in outline, is elongated in a northerly
direction, measuring six miles from north to south and up to two miles east and west. From the south the stock extends northwesterly parallel to the front of the Beaverhead Range, expanding rapidly until it reaches Carmen Creek, where its size diminishes and its direction changes to north-northeast. From there, it extends parallel to the creek for about three miles, reduced to half a mile across, except just beyond the turn where a local westward bulge crosses the ridge into Gold Star Gulch, a prominent tributary of the East Fork of Boyle Creek. The small outlier, which is due west in the valley of the East Fork, is in line with the bulge in the main stock and separated from the bulge by less than half a mile of bridging quartzite.

The granodiorite has no particular distinctive features unless its relatively small and rather uniform grain size may be regarded as distinctive. The rock does show some variation in grain size; but much of it is characteristically medium to moderately coarse-grained with only slight tendency for porphyritic development, which is noticeable only in the more central parts of the body where phenocrysts up to an inch long may be observed. Otherwise, the larger grains rarely exceed lengths of 0.5 inch; whereas average grains, measuring 0.3 to 0.4 inch, are so nearly the same size as to make most of the rock appear equigranular. Because the rock contains less than 15 percent dark minerals, its color varies from light gray to medium gray, with the darker rock largely confined to the marginal parts of the stock.

The stock does possess another significant feature, a conspicuous abundance of darkly colored, xenolithic inclusions of hornblende diorite. Because of their relative abundance and widespread distribution, they must be regarded as an essential component of the stock.

All the essential minerals of the granodiorite are discernible in the hand specimen: quartz, biotite, hornblende, plagioclase (zoned andesine), and in places, microcline. Some of the accessory and secondary minerals, such as sphene and epidote, are also visible; but zircon, apatite, allanite, and magnetite can be recognized only as microscopic accessories. The dark minerals generally compose from 10 to 15 percent of the rock, with biotite generally more abundant than hornblende, except in some of the marginal and more northerly parts of the stock. The zoned andesine (Ab65 to Ab75), the most abundant mineral, generally composes more than 50 percent of the rock but less than 50 percent where the rock shows porphyritic tendencies. The microcline, much subordinate to the andesine, normally composes about 10 percent of the rock, increasing to 20 percent or more in porphyritic facies. Some of the rock in the north end of the stock has scarcely more than accessory amounts of microcline so that in composition it approaches quartz diorite. Some of the porphyritic rock toward the other end of the stock has enough microcline to approach quartz monzonite. Notably conspicuous, the quartz forms 20 to 30 percent of the rock. The sphene and epidote, present in relatively high concentration, each make up several percent of the rock. The
allanite is also notably abundant in some places; but the zircon, apatite, and magnetite are very minor accessories.

The rock shows some prominent endomorphic effects. There has been some local myrmekitic development where microcline has penetrated crystals of andesine. Some of the larger microcline grains hold remnant inclusions of andesine. The andesine and especially the biotite and hornblende show notable penetration and replacement by euhedral crystals of sphene, allanite, and epidote. Some of the plagioclase crystals have been extensively saussuritized or sericitized. The quartz, especially, shows its endomorphic development. Most of it is in large lobate grains that embay and penetrate all the other minerals. The mineral relations are those of a consolidated magmatic rock acted upon and endomorphosed by fluids from deeper sources, which permeated the still hot rock and supplied the materials—notably potassium, titanium, iron, rare earth metals, and silicon—needed to form much of the potash feldspar, the quartz, and the several abundant accessory minerals.

The xenolithic inclusions merit special attention. **Xenoliths** They are represented by dark-gray, fine-grained hornblende diorite, spotted with large, locally abundant crystals of plagioclase similar to those of the granodiorite. As these large "porphyroblastic" crystals become more abundant, the xenoliths show transition into granodiorite. The large crystals give the xenoliths a spotted appearance and somewhat variable texture. Except for these spots, the xenoliths are composed of about 40 percent hornblende, with very subordinate biotite; nearly 60 percent calcic andesine; and accessory orthoclase, quartz, apatite, zircon, and magnetite. The light-colored spots mark the development of large porphyroblasts of andesine of the same kind occurring in the granodiorite. The porphyroblastic andesine has apparently been introduced by a "soaking" process.

Some of the thin sections of the granodiorite reveal shadow outlines of less coarsely crystalline minerals that appear to represent an earlier medium-grained rock similar to the xenoliths, which essentially has been completely replaced by the large crystals of andesine and other minerals that now compose the granodiorite. It seems likely that the xenoliths are the remnants of the chilled, fine-grained marginal facies of an earlier rock converted, except for the residual xenolithic inclusions, into granodiorite by large-scale endomorphic action.

The intrusion of the granodiorite has caused some notable changes in the bordering quartzitic rock, less noticeable along the western than along the eastern border. Along the western border the rock shows only minor increase in grain size and in the quantity of biotite and muscovite, the size and quantity increasing toward the contact. Some potash feldspar has also formed close to the contact, and the rock shows some evidence of silicification.
Along other parts of the stock, however, the contact action, much more pronounced, has led to the local formation of gneiss. According to MacKenzie (1949), who has studied the contact zone in some detail, the effects of heat and igneous emanations vary somewhat from place to place but disappear within 400 feet of the contact. He points out that the rock in the outer part of the zone is leached of its mafic constituents in such a way that the rock is traversed by a series of quartz veinlets, with the mafic materials, chiefly biotite, collected in the center of the "bleached veinlets". This reorganization of the mafites has apparently been the only effect on the rock.

In the inner zone where metamorphism is more advanced, the rock has been changed to a well-banded gneiss, containing visible biotite, muscovite, chlorite, magnetite, quartz, and feldspar. The typical gneiss, according to MacKenzie (1949), contains about 35 percent potash feldspar, 25 percent sericite, 15 percent biotite, 10 percent quartz, 5 percent magnetite, 3 percent clinoclore, and 7 percent coarse muscovite. The quartz and feldspar occur as equigranular, interlocked grains 0.1 to 0.3 mm. in diameter. Felted and radiating sericite is developed along rudely parallel zones. The sericite appears to replace biotite but crowds the biotite aside where it develops into larger grains. The late muscovite grains extend across the earlier biotite.

The contact between the gneiss and the stock is generally gradational over a distance of several feet, but in places the contact has almost knife-like sharpness.

Age of the granodiorite determined from its radioactive accessory minerals, the intrusion cannot be dated, except by correlation with similar rocks whose ages have been established. It is certain that the granodiorite is younger than the Laramide folding, faulting, and regional cleavage, and for that reason cannot be regarded as a distant outlier of the Idaho batholith (pre-Laramide). The rock itself does not possess the mineralogical and chemical characteristics of the rock typical of the Idaho batholith but does show a striking likeness to some of the rock of the Boulder batholith and its satellites (Knopf, 1957, p. 90-95). The hornblende diorite and syenodiorite in the Baker quadrangle have been recognized as identical to certain facies of the Boulder batholith (Anderson, 1957, p. 29), which has been the basis for fixing the age of the diorite and syenodiorite as the same as that of the Boulder batholith. The hornblende diorite is also identical to the xenolithic inclusions in the granodiorite along Carmen Creek. As the xenoliths appear to represent an early consolidated facies of the granodiorite, the granodiorite may also be considered to have the same age as the Boulder batholith. Radioactive accessory minerals give the Boulder batholith an average age of 68 million years (Chapman, Gottfried, and Waring, 1955, p. 607-610), indicating that it was emplaced at or near the close of the Cretaceous. It is probable that the granodiorite along Carmen Creek was also emplaced contemporaneously.
Quartz monzonite

The bodies of quartz monzonite on the Salmon River Mountain slope in the southwest part of the quadrangle are represented by a stock a little larger than the one on Carmen Creek and by a fairly sized dike (pl. 1). The stock is an extension of the one studied and mapped in the Salmon quadrangle (Anderson, 1956, p. 39-42). Though it has an exposed length of 8 miles, 4 1/2 miles of which are in the North Fork quadrangle, and a width of 1 to 1 1/2 miles, its total length is not exactly known, for the body disappears beneath a cover of Tertiary sedimentary rocks about a mile northwest of Salmon. The stock is elongated in a general north-northwesterly direction; but the body shows several local changes in trend—it actually has a zig-zag course—changing alternately from northwest to northeast and back again, each deviation marking a change in the direction of the controlling structures.

The most striking feature of the quartz monzonite is its coarse texture, with grains considerably larger than those which characterize the rock in the granodiorite stock on the other side of the quadrangle. Most of the grains average about 0.4 inch in diameter but some measure up to an inch or more. Lacking also the textural uniformity of the granodiorite, the rock shows marked textural variations within short distances, especially in marginal areas. There the rock may become gneissic and locally porphyroblastic and show transition to augen gneiss. Otherwise, it is coarsely granular with some tendency toward porphyritic development, very conspicuous in places where phenocrysts attain lengths up to 2 inches. Such crystals are contained in a coarse-grained granular matrix composed of grains from 0.3 to 0.4 inch in diameter. Most of the rock in the interior of the stock is gray, but that in marginal areas is moderately dark-gray because of increased biotite content.

The leading minerals of the rock are sodic andesine, microcline, quartz, and biotite; but it also contains an unusually high concentration of sphene and more than normal amounts of zircon and apatite. It also has an abundance of such secondary minerals as sericite, zoisite, and epidote. In general, the sphene composes about 5 percent of the rock, the biotite 10 percent, the quartz 20 to 30 percent, and the andesine and microcline, about equally abundant, most of the remainder. In some of the rock, especially that which is conspicuously porphyritic, the microcline is more abundant than the plagioclase, causing the rock to approach or even to become granite. The two feldspars are readily visible; the plagioclase occurs as dull, chalky, white grains; and the microcline as grayish, generally much larger, glassy grains or crystals. The biotite grains are much smaller than the feldspar crystals, commonly measuring about 0.2 inch in diameter, though a marked tendency to occur in clusters makes the grains appear larger than they actually are. The quartz is easily distinguished by its glassy, somewhat smoky appearance; the abundant sphene, by its golden-brown crystals.
The minerals possess very interesting relations, which are described and discussed in some detail in the report on the Salmon quadrangle (Anderson, 1956, p. 40-41). Their relations clearly suggest replacement origin. Under the microscope, some of the quartz in the rock occurs as aggregates of fairly coarse, interlocking grains surrounded and penetrated at the margin by the feldspars and other minerals. A few of the coarse-grained, aggregate mosaics contain shadow outlines or remnant inclusions of a fine-grained quartz exactly like that composing the Lemhi Quartzite. This fine-grained quartz is quartzite that has not been reorganized or recrystallized to form the larger grains characteristic of the coarse quartz aggregates. Small remnants of such quartz mosaics, not uncommon as inclusions in the other minerals, may occur abundantly as island-like inclusions in the microcline as well as in large lobate grains of quartz that not only retain island-like remnants of the mosaic quartz but also penetrate unevenly into the biotite and the feldspars. These quartz relationships indicate quartz of more than one age, one older than the feldspars and one younger.

The biotite, especially, shows the tendency to occur in clusters in the mosaic, granular quartz where its parallel or subparallel alignment causes the gneissic foliation of much of the marginal rock. As the feldspar content of the rock increases, the quartz mosaics become fewer and smaller, disappearing almost entirely in the more central parts of the stock. At the same time, the habitual clusters of the biotite become less conspicuous: the grains tend to appear interlocked with the feldspar, although actually they are penetrated by the feldspar and usually by large grains of lobate quartz as well.

Unorthodox "igneous" aspects are even more prominent among the feldspars. The sodic andesine generally has good crystal outline, except against microcline and the large grains of lobate quartz. Much of it occurs as saussuritic mixtures of sericite, zoisite, and epidote or as aggregates of fairly coarse sericite. Although the microcline appears to have good crystal outline when observed by the unaided eye, it actually possesses minutely irregular borders that tend to enter between, wrap around, or protrude into neighboring mineral grains. More significantly, the microcline usually retains numerous remnant inclusions of the andesine and mosaic quartz, and less commonly of biotite. Most of the inclusions are mere remnants of once much larger grains; some grains are recognizable only by shadowy outlines. Much microcline has replaced other minerals so that the quantity of andesine in the rock decreases proportionately as the microcline increases. In much of the rock the microcline is perthitic; in some places the boundaries have rims of albite entering into and replacing the microcline.

The bulk of the quartz forms large lobate grains which protrude into the biotite and feldspar. Some of the quartz holds remnant inclusions of biotite and feldspar along with remnants of the aggregate quartz inherited from the quartzite. Some of the
lobate grains are also penetrated or cut by other grains and seams of lobate quartz, a relationship indicating at least two generations of late quartz.

The accessory minerals, such as the sphene, zircon, and apatite, tend toward larger than normal sizes, usually occurring as small crystals in the biotite and andesine, mainly along cleavage lines and grain boundaries. Some of the biotite is virtually littered with crystals of sphene and zircon. Though the sphene tends to favor the biotite, it may also occur abundantly with zircon and apatite in the plagioclase. Epidote, usually not regarded as an accessory mineral, occurs abundantly as large visible grains, usually as a replacement of the biotite and andesine. In the andesine, the sericite generally forms fine-grained aggregates, but some sericite is coarse, and some may be large enough to be classified as muscovite. The larger grains are usually associated with and occur as replacements of the biotite.

The mineral relations indicate that the quartz monzonite was not formed by consolidation of magma but by extensive replacement of a rock which the remnant inclusions indicate was originally siliceous rock of the Belt Series (Belt Quartzite). Before the quartzite's conversion to granitic rock, its small grains of quartz were generally reorganized into much larger ones. Large grains of biotite then formed in the more coarsely crystalline quartz, probably from materials introduced into the rock. At this early stage, the quartzite was transformed into a biotite schist which, with introduction of plagioclase, was converted to a gneissic rock and then, with addition of abundant microcline, to a granitic rock. In these changes the plagioclase formed at the expense of the biotite; the quartz and the microcline, at the expense of all three. Where the substitutions were less complete, the schistose rock was converted to augen gneiss; but generally the replacements of the earlier minerals by younger continued to a more advanced stage so that the rock ended as a granitic variety, ranging from granite to quartz monzonite. As the microcline ceased to form, the accessory minerals and late quartz were introduced into the rock. The accessory minerals, especially the sphene, zircon, and apatite, entered extensively into the plagioclase and biotite, and in some places, into the remnants of recrystallized quartzite as well. The late quartz sent penetrating lobes into all the earlier minerals as well as into the remnant quartzite.

The quartz monzonite thus formed by intense but somewhat incomplete granitization of quartzite, is metamorphic rather than a truly igneous rock. To induce the granitization of the quartzite, such elements as iron, magnesium, calcium, sodium, potassium, aluminum, titanium, zirconium, phosphorus, and silicon had to be introduced into the rock by "granitizing solutions" from deep sources. Entering into the rock, these solutions caused successive development of biotite, andesine, and microcline and then of quartz and the various accessory minerals. Finally, as the solutions changed in composition, they induced the formation of secondary minerals, mainly by alteration of the biotite and plagioclase.
The "granitizing" solutions, exceptionally enriched in potassium, titanium, and zirconium, caused the formation of unusually large amounts of potash feldspar and more than ordinary quantities of sphene and zircon.

The quartz monzonite stock, formerly regarded as an outlier of the Idaho batholith, was thought therefore to have been intruded into Nevadan folds during Cretaceous time (Anderson, 1956, p. 39). Because the folding now appears to be largely the product of the younger Laramide orogeny, the stock is more likely to have been emplaced at the close of rather than during Cretaceous time. Its emplacement during late stages of the Laramide orogeny is suggested by the fact that it shows control by both northeast- and northwest-trending structures, which account for the zig-zag course of the stock. These two structural trends, as the Structural Geology section of the report will indicate, accord with the Laramide structural trends elsewhere in the general region (Scholten and others, 1955, p. 375-384). That correlation of the stock with the main body of the Idaho batholith is not realistic is demonstrated by the marked petrographic and petrologic differences between the bodies. The local quartz monzonite bears little resemblance to the quartz monzonite of the main mass of the batholith. Its textural characteristics, especially its high content of sphene, and to lesser extent, of zircon and apatite, set it sharply apart from the rock of the batholith. Such a high concentration of sphene and other accessories tends to link the rock instead with the Boulder batholith and its satellites.

Dating of the radioactive accessory minerals is the only remaining way to determine the precise age of the local quartz monzonite, particularly with reference to the granodiorite on the other side of the quadrangle. The present evidence indicates that the quartz monzonite is late Laramide but gives no clue as to whether it was emplaced before or after the granodiorite. Its more alkaline character and somewhat greater concentration of sphene suggest that it may be a little later; that it was largely formed by fluids more or less similar to those that caused the endomorphism of the Carmen Creek stock but which acted on the quartzite instead of on a just previously intruded magmatic rock.

_Lamprophyre_

Dikes of lamprophyric character are rarely observed in the North Fork quadrangle, possibly because of their small size and because inconspicuous outcrops are rapidly lost to weathering and concealed by surface debris. Two small dikes were studied, both exposed in the large highway cut along the Salmon River about a mile below the mouth of Fourth of July Creek. These two dikes, each about 2 feet thick with exposed lengths of about 50 feet, are intruded along a zone of complexly fractured quartzite, directed by east-west trending fractures of nearly vertical dip.

In the dike that shows the least alteration the rock is dark gray with a very fine grain, except for some scattered crystals.
and groups of crystals that occur as inconspicuous phenocrysts. The microscope reveals that the rock contains about 20 percent augite as phenocrysts in a very fine-grained matrix of augite, tiny plagioclase laths, magnetite, and chlorite.

The other dike, its rock distinctly greenish-gray, shows more extensive alteration. The rock is also more conspicuously porphyritic, mostly because of its large crystals of quartz and plagioclase and large granules of aggregate calcite. Microscopically, the rock is much like the other, except that the augite has largely altered to calcite or pseudomorphous aggregates of calcite and chlorite. Besides chlorite and magnetite, the only mineral recognizable in the groundmass is plagioclase.

The dikes have the composition of augite diorite lamprophyre.

The lamprophyres are included with the earlier group of intrusives, although proof that they belong to this group is lacking. That they are in an east-west zone of hydrothermal alteration that extends discontinuously from the river into the Challis Volcanics on Dump Creek, suggests that they may belong to the younger group of mid-Tertiary intrusives. Several dikes of quartz monzonite granophyre of mid-Tertiary age also occur in the zone near the top of Napoleon Hill.

Mid-Tertiary intrusives

Foreword

The mid-Tertiary intrusives are altogether different from those of late Cretaceous or early Tertiary age. They form small, scarcely mappable dikes or stock-like bodies of conspicuously porphyritic rock, with the phenocrysts and groundmass reflecting two separate stages of crystallization. One of the intrusives, a dacite porphyry, markedly resembles the dacitic flows in the nearby Challis Volcanics and may have served as a feeder to such flows. Another, a granophyre with the composition of quartz monzonite, has the appearance and character of the Miocene porphyries that are known to have intruded the Challis Volcanics elsewhere not long after their extrusion (Ross, 1934, p. 54-67). Another body that resembles a quartz porphyry seems to be a product of incipient granitization rather than magmatic consolidation.

Dacite porphyry

The small body of dacite porphyry is exposed along the slope and crest of the ridge about one-half mile northeast of the settlement of North Fork (pl. 1). It has been intruded along the zone of a large, high-angle thrust fault which trends northwesterly, more or less closely parallel to the Salmon River before the river makes its abrupt turn to the west at North Fork.

The rock in this small, somewhat thickened, crescent-shaped body is conspicuously porphyritic, with feldspar phenocrysts.
measuring up to 0.4 inch long and those of quartz and biotite, about half as long. They are contained in a grayish, very fine-grained groundmass in which the minerals cannot be distinguished without the microscope. The phenocrysts compose about a third of the rock. The microscope reveals that they are composed of oscillatory-zoned crystals of andesine, numerous corroded and embayed grains of quartz, and completely chloritized crystals of biotite. The microgranular groundmass is almost entirely oligoclase and quartz with much lesser amounts of chlorite and epidote.

**Quartz monzonite granophyre**

Two small, stubby bodies of quartz monzonite granophyre are exposed just below the top of Napoleon Hill on the west margin of the quadrangle. Only the body exposed on the crest of a sharp, river-facing, spur ridge actually extends into the quadrangle (pl. 1).

The rock of these small intrusives is conspicuously porphyritic and contains a considerable proportion of phenocrysts in an apparently fine-grained, slightly pinkish-gray groundmass. Because of the abundance of the dull, chalky feldspar phenocrysts, the rock as a whole appears light gray. The feldspar phenocrysts, which measure up to 0.3 inch long, are accompanied by scattered grains of glassy quartz almost as large, and by a liberal sprinkling of dull greenish biotite and hornblende crystals less than 0.1 inch long. The feldspar phenocrysts are largely sodic plagioclase, together with a few crystals of orthoclase. They are contained in a micrographic groundmass of quartz and orthoclase. It is estimated that the rock as a whole contains nearly equal amounts of orthoclase and plagioclase. Other minerals in the rock include a little accessory zircon and magnetite, and considerable chlorite, calcite, epidote, and sericite.

The nearness of these granophytic bodies to a block of hydrothermally-altered Challis Volcanics in the canyon of Dump Creek just the other side of Napoleon Hill, suggests a possible genetic relationship between the intrusives and the alteration. The granophyres would then be post-Challis and belong to the group of mid-Tertiary granophyres from which they are megascopically and microscopically indistinguishable.

**Replacement quartz porphyry**

The replacement porphyry presents an exceptional case of incipient granitization in which quartzite has been partly transformed into a porphyry-like rock. This transformation is thought to have been accomplished by granitizing solutions from Tertiary magma channeled upward along a major zone of structural weakness.

This unique porphyry, along the zone of the major thrust fault extending northwesterly along the Salmon River, is exposed in the first highway cut about a mile southeast of North Fork. The spot is marked by a broad zone of fractured, highly iron-stained rock, most of it quartzite that has been altered and
impregnated by small crystals of pyrite which, at the surface, have weathered to produce conspicuous buff and brownish stains. The "porphyry," which forms only a small part of the altered rock—less than 100 feet along the face of the highway cut—is too small to show on the map.

Where the weathered material has been blasted away, the granitized rock is light gray; some of it resembles granite; more of it looks like a quartz porphyry; but all of it contains finely disseminated pyrite, with larger crystals along fractures. The rock resembling porphyry is studded with large, conspicuous quartz phenocrysts measuring up to 0.4 inch in diameter in a matrix of smaller, chalky-white to gray feldspar crystals. Where the quartz phenocrysts are lacking, the rock resembles granite. Rock of this kind merges with or shows transition into quartzite, retaining in places the bedded structures of the bleached quartzite.

Microscopic studies reveal that the matrix of the porphyry is albitized quartzite, in places somewhat sericitized; this matrix is impregnated with or replaced by irregularly scattered, much larger grains of quartz, andesine, and biotite (largely altered to chlorite and epidote). The quartz tends to build large, ovoid grains; but the andesine shows good crystal development, except where the crystals are so closely packed that one interferes with another. Where the feldspar grains are closely packed, the rock resembles a coarse-grained granodiorite. Otherwise the matrix is distinctly hybrid with as much albitized quartzite as andesine, both of which are overshadowed by the large grains of quartz. As in normal igneous rocks, the replacement porphyry contains accessory zircon and magnetite.

The solutions that changed the rock apparently carried not only an appreciable concentration of calcium, magnesium, sodium, potassium, aluminum, and zirconium, but a much greater concentration of silicon, iron, and sulfur. The addition of these elements induced the formation of the plagioclase feldspar, the biotite, the quartz, the several accessory minerals, and the chlorite and sericite. The abundant pyrite suggests that these channelized, granitizing solutions were intermediate between those which accomplish large-scale formation of granite and those which deposit metalliferous ores.
STRUCTURAL GEOLOGY

FOREWORD

The structural relations of the rocks in the North Fork quadrangle are complex, largely because of superposition of structures associated with several crustal disturbances. These disturbances began near or after the close of Precambrian time but left little or no mark on the rocks in the quadrangle, until the close of the Mesozoic when the Belt rocks were complexly deformed by forces associated with the Laramide orogeny. Crustal disturbances continued intermittently in early and mid-Tertiary time, leaving their mark on the Tertiary as well as on the older rocks. The more complicated structural relations of the older rocks are considered separately.

STRUCTURES IN THE OLDER ROCKS

General features

Because the Belt formations are so thick and contain so few reliable horizon markers, details of structure are difficult to trace. This difficulty is increased by large areas with few, poor exposures to provide clues to the structural relations. The available data, however, indicate the presence of locally prominent northeast-trending folds; of regionally prominent northwest-to north-trending folds; of northwest-trending low-angle thrust faults, high-angle thrust faults, high-angle normal faults; and of some faults of other kinds and directions. Except for the last, these structural features are listed in sequence from oldest to youngest. Where the northwest trends are superposed on the northeast folds, the structural pattern is extremely complicated.

Northeast folds

The areas of northeast folds appear as isolated windows in what is otherwise a structural frame dominated by northwest-trending structures. These windows are scattered from the southwest to the northeast corners of the quadrangle. One of the larger exposures, on the lower Salmon River Mountain slope (pl. 1), is about 5 miles long in a northerly direction and less than a mile to 2 1/2 miles wide. Its boundaries are very irregular with abrupt changes in strike of the strata across the boundary. Near the south end of the exposure the beds strike about N 50°-60° E, dip 35°-55° SE, to form the northwest limb of a broad synclinal fold overturned somewhat to the southeast (with its axial plane dipping 40°-60° NW). Near the river the synclinal structure is interrupted by minor anticlinal folds also overturned to the southeast. Followed northward, the fold trend swings to a more northerly direction and the minor folds become less open and more closely spaced, in places becoming isoclinal and overturned to the east (pl. 10, sec. G-G). This change from open to tight folds
seems always to be associated with changes in trend from northeast to a more northerly direction. The strike of the strata bordering the irregular windows is always northwest and commonly departs from that within the window by about 90°. The remarkably sharp boundary line separating the northeast folds from the northwest structures appears to be fault-controlled. In places the northwest structures are cappings on the northeast folds.

Several small windows also appear between the Salmon River and the band of Challis Volcanics to the northeast. In these windows the beds dip southeast at angles of 20 to 30 degrees. These scattered exposures, sharply interrupted by intervening masses of rock with northwestward trends, do not reveal fold characteristics.

Appearing in the Beaverhead Range at the base of the frontal escarpment near Fourth of July Creek and continuing to the north boundary of the quadrangle, is the largest window of northeast-trending rock. This window, involving the Swauger Quartzite, is long but irregular. Up to 4 miles across in places, it reveals a broad synclinal fold somewhat overturned to the southeast (pl. 10, sec. A-A). As across the river, the trend of the fold is essentially at right angles to the trend of the bordering, northwest-trending folds. The synclinal fold, cut by some prominent faults, is locally separated from the northwest structures by high-angle faults. Otherwise, boundary relations are much the same as west of the Salmon River.

The overturning of the folds to the southeast implies the work of northwest-southeast forces, with the dominant force acting from the northwest.

Northwest folds

The dominant structural feature of the quadrangle is probably the northwest-trending, complexly faulted anticline whose broken crest closely parallels the Salmon River to and beyond North Fork (pl. 1 and 10, sec. C-C and D-D). It appears to be a fold of major magnitude, perhaps an anticlinorium, with its much faulted limbs extending beyond the boundaries of the quadrangle. Because its axis is so near the Salmon River, the fold may be referred to as the Salmon River anticline. Its southwest limb lies entirely within the Salmon River Mountains. Except for local interruptions by minor folds on its flanks, the beds there dip southwest at angles of 30° to 40°, or even more where increased by faults. The northeast limb extends far into the Beaverhead Range, and beyond the Continental Divide in places. Everywhere east of the river, except near the northeast boundary of the quadrangle, the beds dip northeast at moderate angles, steepened in places by faults. Near some of the faults the beds have been complexly folded or crumpled and commonly overturned. The beds on both flanks strike about N 40° W with some departure to either side. Near the north boundary of the quadrangle, the beds assume a more northerly trend.
Minor parallel folds occur sparingly on both flanks of the anticline. Most of these folds may be traced for only a short distance before their plunge causes them to disappear. The more prominent plunge appears to be to the southeast. The most notable of the minor folds are in the northeastern part of the quadrangle, where the structure appears to be less complex and the broad anticlinal fold gives way to more gently folded structures (pl. 10, sec. D-D).

The northeast-southwest compression that produced the northwest-trending structures severely complicated, and in part obliterated, the structural pattern set up by the earlier northeast-southeast forces. Apparently, only the more prominently folded structures of northeast trend were able to survive the later folding; but even some of these structures, such as the more tightly compressed folds in the window west of the Salmon River, were realigned in a more northerly direction. The realignment apparently reflects the local response of some of the less competent rocks in the Lemhi Quartzite; an adjustment to the new set of forces by further compression and tightening of the more open, earlier-formed folds.

Low-angle thrusts

Low-angle thrust faults appear to be associated with the windows in which the folds of northeast trend are exposed. Except in O’Neill Gulch between Fourth of July and Wagon hammer creeks, the faults are not easily detected; their presence is largely inferred from the irregular contact discordance of the northeast and northwest structures and from the apparent disappearance of the northeast-trending folds beneath those of northwest trend, the latter in places capping the ridges underlain by the northeast folds (pl. 1 and 10). The relations are further complicated by much high-angle faulting along the margin of the window exposures. In structure sections, the only way the structural relations may be explained is by means of low-angle thrusts. Because of similar lithology and absence of diagnostic horizon markers, the magnitude of the low-angle thrusting is not known, but the displacements may be expected to be as much as several miles. The low-angle thrusting followed the northwest folding and was apparently localized along the structurally weakened boundaries of the northwest folds where they were superimposed on the northeast folds.

High-angle thrusts

The high-angle thrusts play a more prominent role in the structural development of the area than do the somewhat earlier low-angle thrusts. Of major magnitude, some of them may be traced for miles. Striking in a northwesterly direction about parallel to the northwest folds, they tend to veer in a somewhat more westerly direction. Dipping to the southwest at angles near 30°, these faults are generally marked by broad zones of intense deformation, shown by the development of sheared and schistose rocks and
by prominent drag folds and other features characteristic of fault zones.

Several of these high-angle faults are singled out for more detailed description. Extending into the southeastern part of the quadrangle (pl. 1), the Miner Lake fault, named by MacKenzie (1949), may be traced into the upper valley of Carmen Creek where it is cut off by a fault of northerly trend. The Miner Lake fault has brought the Lemhi Quartzite on the southwest against the Swauger Quartzite on the northeast. Intense crumpling has occurred along the fault, especially in the phyllitic quartzite of the hanging wall. The bedding has been destroyed and the rock locally converted to schist, or otherwise silicified and impregnated with magnetite and specular hematite. The fault zone has also localized dike intrusion.

An apparent continuation of the Miner Lake fault appears on the west side of Carmen Creek on the middle frontal slope of the Beaverhead Range. Sheared phyllitic beds of the Lemhi Quartzite also lie on and against the light-colored beds of the Swauger Quartzite. The fault may be traced about 2 miles to the northwest, where it is cut off and lost against a more recent normal fault. This probable extension of the Miner Lake fault may have considerable throw, perhaps as much as several thousand feet. The offset by the northerly trending fault along Carmen Creek, which also in part directed the intrusion of the granodiorite stock, is about 1 3/4 miles horizontally, although the actual displacement may be much less should the fault be normal with downthrow to the east.

Another high-angle thrust fault emerges from beneath the blanket of Challis Volcanics about two miles above the mouth of Little Silverlead Creek, extends across the low pass into Trail Gulch, and thence on across the North Fork of the Salmon River (pl. 1). The course of the fault is marked by a broad zone of highly disturbed schistose rock. The impure quartzitic rock of the footwall and the overlying reddish beds of the basal Swauger, have been forced into an overturned anticline whose eastern limb is vertical (pl. 10, Sec. B-B'). Projected to the southeast, the fault passes under the Tertiary volcanic and sedimentary rocks; if continued, it would reappear and align with the faulted end of the Miner Lake fault on the East Fork of Boyle Creek. The old valley now occupied by the volcanic and younger rocks was probably in part carved along this fault.

Still another probable high-angle thrust fault emerges from beneath the Challis Volcanics and younger rocks just above the mouth of Kriley Creek to extend northwesterly along the northeast side of the Salmon River to and beyond the settlement of North Fork (pl. 1). This is the large fault which has bisected the crest of the Salmon River anticline. The rock along this fault has been extensively fractured over widths of 100 yards. Near North Fork, where the dark-gray Lemhi Quartzite has been irregularly bleached, it resembles in small areas the Swauger Quartzite. A mile southeast of North Fork, where the fault zone has been invaded by granitizing
solutions, the rock in part has been changed to a highly pyritized quartz porphyry and granite. For some distance to the southeast the fault may be traced by the highly iron-stained rock resulting from the oxidation of the pyrite introduced along the fault zone.

Near the mouth of Wagonhammer Creek, the fault zone has been recently exposed by landsliding of shattered, hanging-wall rock down upon the highway. To clear the highway of this landslide, localized along the weakened fault zone, required 2 power shovels and a fleet of trucks working steadily for several months during the late spring and early summer of 1938. Southeast of Wagonhammer Creek, where the fault is generally concealed by surface debris, it is not so easily traced, but may be followed to Kriley Creek where it shows minor offsets by transverse faults. In several places it cuts and bounds the windows of northeast-trending folds. Northeast of North Fork the fault zone is invaded by a body of dacite porphyry. The fault apparently controls the general alignment of the Salmon River after it begins its meandering course across the rim of the Salmon Basin.

Other high-angle thrusts, most of them in the Beaverhead Range, far out on the flanks of the Salmon River anticline are inferred from rock relations on either side and from topographic abnormalities. The size of these faults remains unknown, but some of them may be of more than minor magnitude. Many small faults probably escaped mapping.

The general pattern of these high-angle thrusts suggests possible imbricate structure.

**High-angle normal faults**

The high-angle normal faults are among the most striking of the structural features. They are somewhat varied as to age and direction, although all of them appear to be younger than the northwest-trending folds and thrust faults. The principal normal faults trend north-northwest, slicing across the earlier northwest trends at an appreciable angle. Other smaller faults trend north-easterly, perhaps as a complimentary set, and in part cause minor offsets in the northwest-trending faults.

Most of the high-angle normal faults are crowded into a north-northwest-trending zone about two miles wide, which appears from beneath a cover of Tertiary and Quaternary formations near Boyle Creek to extend on toward the northwest corner of the quadrangle. This zone of faults separates the higher Beaverhead Range from the lower country on the southwest. The structural zone is a complex of more or less parallel, locally branching faults, most of which dip steeply southwest, though a few dip in the opposite direction. Prominently reflected in the topography, these faults may be readily traced by the alignment of saddles across ridges, and by the right-angle pattern of minor gulches to some of the larger streams which cross the fault zone. Only the more prominent of these faults are shown on the map. The topographic relations suggest many other smaller faults.
The prominent structural zone is bounded on the southwest by an especially well-defined fault which, because of its control on the drainage in Carls Gulch in the northwestern part of the quadrangle, may be referred to as the Carl fault. The fault may be easily traced by the alignment of saddles and gulches from the North Fork of the Salmon River near the North Fork Ranger station, south-southeast to Boyle Creek where it disappears beneath a cover of Tertiary rocks. Northwest of the North Fork of the Salmon River, its course is concealed beneath a cover of Tertiary volcanics. Apparently dipping northeast, this border fault has dropped the light-colored beds of the Swauger Quartzite against the reddish-tinted basal beds, representing a possible stratigraphic throw of several thousand feet. For part of its course, it is backed by higher country of its southwest side.

The broad, structural zone is also bordered on its northeast side by the prominent Stein fault, which may be traced several miles up Stein Gulch and one of its tributaries, then southeasterly across the upper drainages of Little Silverlead, Wagonhammer, and Little Fourth of July creeks to Fourth of July Creek, possibly joining with another fault (Beaverhead fault) near Boyle Creek. The Stein fault, dipping southwest, has had considerable influence on the alignment of drainage along its course. For much of its distance, it is backed on its northeast side by higher mountain ridges which rise much like an escarpment.

The country between the Carl and Stein border faults resembles a complexly faulted graben, with most of the faults dipping southwest—a few northeast—to give the more central block the aspect of a horst.

A prominent fault emerging from the complex Beaverhead fault zone, continues southeastward along the base of the range to become one of the most impressive faults of the district. This fault, which blocks out so much of the Beaverhead Range, is more or less directly responsible for the steep frontal escarpment. It enters from the southeast corner of the quadrangle through a deep saddle bordered on the southwest by a hill of Swauger Quartzite that is hidden under a cap of Tertiary sedimentary rocks and alluvial and glacial materials; on the northeast it is bordered by the steep frontal slope of Lemhi Quartzite. North of Freeman Creek the fault passes beneath a cover of terrace gravels (pl. 1) but reappears at the surface between the mouth of Davis Canyon and Carmen Creek, where it forms the boundary between the down-dropped block of Swauger Quartzite and the Lemhi Quartzite of the main range. For the next several miles the trace of the fault is concealed by surficial debris, but the fault reappears just before reaching Gold Star Gulch where more of the Swauger Quartzite is found against the Lemhi Quartzite. Near the East Fork of Boyle Creek the fault causes wedging and disappearance of the Lemhi Quartzite; from there on, the Swauger Quartzite forms both the escarpment wall and the lower ridges extending out from the base of the range. The fault may be traced through deep saddles across Boyle Creek and on to Fourth of July Creek, where the trace is
interrupted by a cover of Quaternary deposits beyond which the fault seems to diminish in size and become one of the smaller faults of the complex Beaverhead fault zone. The fault appears to branch, however, before reaching Fourth of July Creek, the split branch extending obliquely in a more northerly direction to continue on as the Stein fault.

Scattered, high-angle normal faults have been mapped elsewhere in the quadrangle, some in the Salmon River Mountains but most in the Beaverhead Range. These faults are not as prominently displayed as those along the Beaverhead front nor are they as well known. Trending in more westerly directions, essentially parallel to the thrust faults, some of the normal faults may be cut off by those of more northerly trend. A few faults also trend in a general north to northeasterly direction. Some of these, which trend about due north near Boyle Creek, are cut off abruptly on the south by the Beaverhead frontal fault. East of upper Carmen Creek, a fault striking N 20° E cuts off and displaces the Miner Lake fault, to disappear in turn against the Carmen Creek stock. A similar fault may have directed the northeast-extending prong of the Carmen Creek stock. These few northerly trending faults appear to be older than most of the other normal faults.

The north or north-northeasterly and the more westerly-trending, high-angle normal faults, definitely older than those of the Beaverhead fault zone, appear to be essential components of the northwest-trending structures. On the other hand, the members of the Beaverhead fault zone are superposed on these structures but otherwise have no relation to them either in time or origin.

**Cleavage**

Although the cleavage is a fairly conspicuous structural feature in these older rocks, it has received only cursory attention. In some places it is more conspicuous than the bedding. Most prominently developed in the more impure beds of the Lemhi Quartzite, this structure is rarely conspicuous or even observable in the purer more competent beds of the Swauger Quartzite. The cleavage seems to accompany the folding; and because there are two sets of folds (northeast and northwest), there are also two sets of cleavages.

The cleavage associated with the northeast folds strikes N 30° E and dips 40°-60° NW. Cutting thus across the dip of the beds at a considerable angle, the cleavage offers contributory evidence that the beds form a part of an asymmetrical syncline overturned to the southeast, its axial plane conforming closely with the dip of the cleavage. The relations are clear: the cleavage was produced by the same forces that produced the folds; it developed in response to strong compressive forces acting chiefly from the northwest. Where these northeast folds have been more severely disturbed by forces causing the northwest-trending structures, the northeast cleavage becomes obscure, is even obliterated, and a northwest cleavage is imposed on the rock.
The most widespread and generally conspicuous cleavage is associated with the northwest folds. Particularly pronounced in the impure beds of the Lemhi Quartzite along the front of the Beaverhead Range, the cleavage is locally conspicuous in parts of the Salmon River Mountains. Regional in scope, it always strikes in a northwesterly direction and always dips to the southwest at angles of 35° or more, showing abnormally high dips in segments of faulted rock. Along the front of the Beaverhead Range the cleavage is so strongly developed that it has induced the formation of dip slopes. Presumed to have been associated with and to have accompanied the northwest folding, the cleavage was formed at the same time as the folds and by the same northeasterly directed forces.

Joints

The older rocks are everywhere closely and prominently jointed, a structural feature locally as conspicuous as the cleavage, and in places, far more so than the bedding. The joints slice through the rocks in several preferred directions to establish a more or less definite regional pattern closely related to the folding. The pattern comprises well-developed systems of strike and dip joints, one or the other of which may dominate locally. Parallel to the strike of the folds are two sets of strike joints, one of which dips southwest, the other northeast. The dip joints also comprise two sets of northeast-trending joints, one of which dips northwest, the other southeast. The dip joints, in places much more highly developed than the strike joints, compose in the Beaverhead Range the most consistent joint system. In some places there are also joint sets of other trends. Locally, the joint sets may be so highly perfected that the rock assumes a sheeted structure, resembling from a distance prominently bedded rock. In other places the rock is broken into irregular, angular blocks.

Age of deformation

The local, structural relations indicate several crustal disturbances since the end of Belt sedimentation; but the data available within the quadrangle supply little information about the time at which these structural events took place. All that is certain is (1) that northeast folding was produced by northwest-southeast forces; (2) that northwest folding was produced by southwest-northeast forces and was followed successively by low-angle thrusting, high-angle thrusting, and high-angle normal faulting under the later influence, apparently, of the same southwest-northeast forces; and (3) that, still later, high-angle normal faulting was superposed on the earlier structures, apparently by an entirely different set of forces. In order to date these different events, it is necessary to consider the regional framework and correlate local structures with similar structures elsewhere for which dates have been established.

In the Salmon and Baker quadrangles, where the folding preceded the emplacement of supposed outliers of the Idaho batholith,
it was presumed (Anderson, 1956, p. 49; 1957, p. 37-38) that the major deformation was associated with the Nevadan orogeny of late Jurassic time and that some intensification of the folding and additional faulting took place during the Laramide orogeny at the close of Cretaceous time. Recent studies in the region to the south (Scholten and others, 1955) have raised doubts about this dating: how much, if any, of the formation is Nevadan? and is not most, or all, of the folding Laramide? A critical review of the problem is in order.

In his studies in the Borah Peak quadrangle some miles to the south, Ross (1947, p. 1128-1129) suggests that the open folds of northerly trend in the Belt rocks throughout the Lemhi Range originated in late Precambrian or early Paleozoic time and that the structural features of northwesterly trend in the old rocks represent effects of much later deformation in which Paleozoic rocks were folded. The older rocks are regarded as so thoroughly competent that structures once formed in them would not easily be obliterated by later movements. Because Belt rocks in western Montana are known to have been deformed before Cambrian beds were deposited on them, Ross considers that the folds in the quartzite in the Lemhi Range are probably of similar date; or that since no Cambrian beds have been recognized locally, the deformation might be as late as that which produced a post-Cambrian unconformity in southeastern Idaho and neighboring regions. As for the Paleozoic rocks, he points out that they had been folded prior to emplacement of the Idaho batholith (Cretaceous) and again during the emplacement of the batholith, hence in Jurassic and Cretaceous time. The northwest foliation in the Belt rocks is regarded as a consequence of these late Mesozoic disturbances.

That there was a crustal disturbance which involved the Belt rocks in early Paleozoic time is definitely established. Scholten (1957) has pointed out that southward in the Beaverhead Range a sharp, angular unconformity truncates the Belt rocks and that the Ordovician Kinnikinic quartzite was deposited on the truncated Belt strata with an angular difference of 20 to 40 degrees. He speaks of the disturbance that gave rise to this unconformity as the Skull Canyon disturbance and asserts that the uplift or disturbance took place prior to Middle Ordovician time, with the center of uplift on the west slope of the Beaverhead Range. Shockey (1957, p. 10) also points out that the Precambrian rocks in the Leesburg quadrangle were warped during the pre-Middle Ordovician Skull Canyon disturbance and that locally there is an angular discordance of 25 degrees between the Belt strata and the Upper Ordovician Kinnikinic quartzite. Shockey's studies further reveal that the major deformation came later and that both the Precambrian and Ordovician rocks were about equally involved in late Mesozoic deformation, during which both were deformed into a reverse-faulted synclinorium trending approximately N 45° W. Apophyses supposedly related to the Idaho batholith were emplaced after the major deformation and dynamic metamorphism, but Shockey follows Earle (1951) in regarding the eastern margin of the batholith as younger than the rest and the deformation as intermediate between Nevadan and Laramide. He postulates that by the time of emplacement of the
local granitic rocks, the general late Mesozoic orogeny had migrated eastward from the Leesburg quadrangle and that some of the structures in the granitic rock were formed while pronounced Laramide deformation was occurring farther east, the batholith apparently protecting the local region from intensive folding and faulting.

The Skull Canyon disturbance must have affected the Belt rocks in the North Fork quadrangle, but no Ordovician rocks remain to afford any clue as to the magnitude or character of that deformation. The early northeast folding, which does not accord with Nevadan trends, is probably not a manifestation of the Skull Canyon disturbance but may have come into existence during the early part of the Laramide orogeny.

Attention may now be directed to the structural relations in the southeast end of the Beaverhead Range and of the mountains to the east, which were beyond reach of the Nevadan orogeny, and where the major structural features since the close of the Precambrian are known to be Laramide (Scholten and others, 1955). Here the post-Paleozoic structure is characterized by northeast folds overturned to the southeast, by northwest folds overturned to the northeast, by northwest low-angle thrusts, by northwest high-angle thrusts later than the low-angle thrusts, and by still later block faults. Except for the block faults, the folds and faults are all products of the Laramide orogeny at the close of Cretaceous time. According to Scholten and others (1955), the Laramide orogeny began with northeast folding induced by northwest-southeast forces. These folds, overturned to the southeast, were probably formed during the Paleocene. This earlier stage of the orogeny was followed by the deposition of the Beaverhead conglomerate. The orogeny then continued, but forces were from southwest-northeast directions, and the northwest folding and thrusting (first the low-angle thrusts and then the high-angle thrusts) were superposed on the earlier northeasterly structures. This later stage of deformation extended into or occurred during the early part of the Eocene.

The structural development in the North Fork quadrangle appears to parallel that in the Lima region: the southern part of the Beaverhead Range and the mountains to the east (Scholten and others, 1955). Moreover, if the northwest structures in the Lima region were projected along their trend, they would continue northwest along the Beaverhead Range into the North Fork area. There is thus good reason to believe that the northeast and northwest folding and the northwest thrusting in the North Fork area are associated with the Laramide orogeny and that these older rocks probably escaped much of the Nevadan deformation.

Assigning the local deformation to the Laramide orogeny has some regional implications that necessitate a revaluation or modification of some current views about the part played by the Nevadan orogeny in structural development some distance east of the Idaho batholith as well as of the part played by the batholith
itself. The quartz monzonite stock on the Salmon River Mountain slope thus cannot be a Cretaceous outlier of the Idaho batholith, as formerly presumed, but must be one of the later intrusives associated with the Laramide orogeny, perhaps a distant satellite of the Boulder batholith. The fact that the rock of the stock is so unlike the quartz monzonite of the main Idaho batholith tends to confirm a lack of genetic and age association. The data appear to be in accord with the general concept of eastward migration of deformation and intrusion during the latter part of Mesozoic time (Lindgren, 1915, p. 261-263; Thom, 1923, p. 4-7; Ross, 1928, p. 691).

Just where the Nevadan folding leaves off and the Laramide folding begins remains an unsolved problem. Where the main mass of the Idaho batholith invaded Nevadan folds, its emplacement is reported to have caused additional deformation (Upleby, Westgate, and Ross, 1930, p. 61-71; Ross, 1936, p. 376-381; Ross, 1938, p. 73-83) that extended as much as 50 miles from its eastern border (Ross and Forrester, 1958, p. 33). As a result, the already folded rock along the intrusive boundary is reported to have been twisted and broken to conform to the shape of the batholith, while the existing folds at greater distances from the boundary had new folds of different trends superposed on them, with the rocks contorted, overturned, and broken (Ross and Forrester, 1958, p. 33). The deformative effects of the batholith carried into the Borah Peak quadrangle, where Ross (1947, p. 1126) reports that the thick section of Paleozoic rocks was deformed by two separate disturbances, in a manner that recalls the structures immediately east of the batholith, but in this case, with the folds more numerous and closely spaced: the Paleozoic rocks were folded into closely spaced, asymmetrical anticlines, locally broken by thrusts at and near their crests; later deformation then twisted some of the folds to produce thrusts of lower dip and greater extent. Ross believes that the original tight folds may have preceded the emplacement of the batholith farther west, whereas the later twists and low thrusts resulted from deformation during the long period in which the batholith came to place and adjusted itself (Ross, 1947, p. 1126-1127). He considers the possibility that both deformative episodes may have occurred slightly later than the corresponding events close to the batholith but believes that the two deformations near the batholith may have taken place in Jurassic and Cretaceous time respectively.

In the light of what is now known of the structural development in the region east of the Borah Peak quadrangle (Scholten and others, 1955) and northward in the Beaverhead Range, one should inquire whether the later deformation in the Borah Peak quadrangle may not be Laramide rather than the product of batholithic forces. The geologic map of the Borah Peak quadrangle shows a large northeast-trending structure not mentioned in the text of the report. This northeast fold, involving the Paleozoic rocks, extends diagonally across the southern part of the Donkey Hills into the Lemhi Range. The presence of this structure in a setting otherwise composed of rocks of northwest trend, suggests a
situation not unlike that in the North Fork quadrangle or in the Lima region (Scholten and others, 1955). Unless the northeast structure in the Borah Peak quadrangle can be explained by movement of the Paleozoic rocks around a buttress of rigid Precambrian rock (the Swauger Quartzite itself appears to partake of part of this structure), the later deformation may indeed be related to the Laramide orogeny.

STRUCTURES IN THE TERTIARY ROCKS

Foreword

Deformation since the close of the Laramide orogeny has, except for important movement along faults, been mild and has involved more or less gentle folding and warping. Many of the high-angle faults, especially those along the front of the Beaverhead Range, which were active during the earlier parts of the Tertiary, probably had much to do with forming the basin in which the Tertiary sediments accumulated as well as the higher lands from which the sediments were derived.

The structures regarded as Tertiary are those which have involved the Tertiary volcanics and sedimentary formations. In these formations structural disturbances are indicated more by the presence of marked, angular unconformities and tilted beds than by always recognizable folds or faults. The relations indicate considerable structural unrest throughout much of the early and middle part of the Tertiary.

Folds

The exposures of Tertiary formations are too restricted to provide much background for recognition of consistent fold patterns and trends. The relations of the different formations suggest a condition of marked crustal instability characterized by abrupt changes in the direction from which deforming forces were applied. Each of the Tertiary formations has a structural character peculiar to itself.

Kriley Formation

The Kriley Formation shows only moderate folding. The beds strike northwest but not at precisely the same angle as the older Belt rocks nor as the flows and bedded pyroclastics of the younger Challis Volcanics. Near the Salmon River the dip of the Kriley beds in the more southerly exposures is 20° NE; but with increasing distance from the river, the dip decreases to 10° NE and locally flattens to form a shallow, nearly flat geosyncline (pl. 4 B).

The trend of the beds indicates deformation by forces acting from a southwesterly direction, from which came the forces that produced the northwest trends in the Precambrian Belt rocks during
the later stages of the Laramide orogeny. It is possible that the Kriley Formation was deformed at the same time. If so, the formation would have to be the equivalent of the Beaverhead conglomerate-exposed farther south in the Lima region (Scholten and others, 1953, p. 368). If not, it would mean that the Kriley Formation had been deformed by later recurring forces from the same general southwesterly direction.

Challis Volcanics

Where structural relations may be observed, the tilted flows and beds of the Challis Volcanics strike northwesterly and dip 25°-35° NE. Folds may be present but were not positively identified. The persistent northeasterly dip of the flows and intercalated pyroclastics suggests control by faults rather than by folds and that the tilt in considerable part may have been caused by downward movement along faults bordering the Beaverhead Range.

Kenney Formation

Unlike the other Tertiary formations, the Kenney has not responded to forces from a southwesterly direction. Instead, the folds are in a northeasterly direction and in this respect are like the northeast-trending folds formed during the earlier stages of the Laramide orogeny. Locally the beds form a broad, open syncline, with its axis more or less closely aligned with Carmen Creek to the mouth of Freeman Creek and thence extending to the mouth of Davis Canyon (pl. 1). On the northwest limb of the syncline the beds dip 22°-27° SE toward Freeman Creek; whereas on the other limb, the beds dip 11°-15° NW (pl. 5 B).

The northeast trend of the beds characterizes the Kenney Formation through the Salmon (Anderson, unpublished data) and Baker (Anderson, 1957, p. 38) quadrangles. The folding is apparently the product of northwest-southeast forces, with the more dominant force from the northwest.

Geertson Formation

The Geertson Formation rests with marked angular discordance—up to 20 degrees—on the eroded beds of the Kriley and Kenney Formations, and locally on the Challis Volcanics. The Geertson Formation has been gently warped, except along the base of the Beaverhead Range where northeast dips are accentuated, perhaps by faulting against the range. Otherwise, the beds are involved in a broad, synclinal structure whose axis, striking a little north of west, crosses Boyle Creek at about the junction of the two main forks. Northeast of the axis, the beds dip about 30° SSW; whereas southwest of the axis, they dip about 30° NW. Close to the Beaverhead Range from Badger Creek southeastward, the dip increases to 30° NE. Southeast of the quadrangle, the Geertson Formation continues its prominent northeasterly dip toward the Beaverhead Range, its strike changing from west-northwest to northwest, more or less parallel to the front of the range. It appears that the
broad fold has been produced by forces acting north-northeast and south-southwest. The change in trend to northwest along the base of the Beaverhead Range suggests either downfaulting along the base of the range or a reorientation of the forces to a more northerly direction because of the buttress resistance of the older rocks.

**Kirtley Formation**

The Kirtley Formation is separated from the Geertson and Kenney Formations by a marked, angular unconformity which is particularly striking in the case of the Kenney Formation whose trend is at right angles to that of the Kirtley. Striking northwest, the Kirtley beds have been deformed into a broad, shallow syncline with beds northeast of the synclinal axis dipping up to 12° SW and southeast of the axis, up to 10° NE. Because the fold axis extends about due northwest, the forces responsible for the shallow fold must have been directed northeast-southwest at a considerable angle to the more northerly forces that produced the broad warps in the Geertson Formation.

**Faults**

Faulting, generally of minor magnitude, is fairly widespread in the Tertiary formations; but because of poor rock exposures, most of the minor faults are hard to detect; and because alluvial materials cover those large enough to direct the drainage, they too are not readily evident. Faults which may have been involved in the deformation of the earlier Tertiary formations have largely been concealed beneath younger Tertiary formations and cannot be detected or mapped. The faults are most numerous in the Challis Volcanics; as would be expected, they are progressively fewer in the succeeding sedimentary formations.

Several faults in the Challis Volcanics are entered on the geologic map (pl. 1). These faults, which have had a marked influence on the drainage pattern, may be readily traced by the alignment of streams and ridge saddles. Some of these faults trend only slightly west of north; others trend in west-northwesterly directions. The displacement on these faults is sufficient to cause abrupt disappearance of key flows and pyroclastics.

Some of the faults along the Beaverhead fault zone, probably active long into the Tertiary, may have had a part in providing the higher land which supplied the Salmon Basin with its sedimentary deposits. The torrential nature of the Kenney and Geertson Formations suggests considerable movement along the faults from time to time to provide the relief necessary for the development of such deposits.

**Age of deformation**

Because of the present scarcity of time markers, the structural events of the Tertiary are difficult to date. The
geomorphic record indicates extensive erosion after the Laramide orogeny, with the formation of a widespread erosion surface of little relief. However, by the time the Challis Volcanics (Oligocene) were extruded, the local surface had been rather deeply dissected, which implies a crustal disturbance involving considerable uplift, possibly accompanied by warping and faulting.

After the accumulation of the Challis Volcanics, marked structural disturbance involved notable uplift (probably associated with faulting) which initiated the torrential accumulation of much of the Kenney Formation. This disturbance probably took place at or near the close of the Oligocene. Another marked crustal disturbance, perhaps in lower Miocene time, interrupted the Kenney sedimentation to provide the local, also torrential, accumulation of the Geertson Formation. Still another structural disturbance, apparently near the middle of the Miocene, put an end of the accumulation of the Geertson sediments and prepared the stage for the deposition of the Kirtley beds in middle Miocene time or later. Just when the Kirtley beds were deformed is not yet known, though possibly it was later, during the Miocene or at the close of the Pliocene. The geomorphic record indicates perhaps some active faulting along the Beaverhead Range into the early part of the Quaternary.
GEOMORPHIC DEVELOPMENT

SUMMARY STATEMENT

This part of Idaho is believed to have been exposed to sub-aerial erosion since the end of the Paleozoic. The results of much crustal deformation during this long interval have been reflected in varying degree in the present topography. After the orogeny at the close of the Mesozoic, erosion of the much deformed rocks produced a widespread erosion surface that began to be dissected before the extrusion of the Challis Volcanics. This pre-Challis erosion surface is the oldest geomorphic feature sufficiently preserved to influence the present topography. Erosion continued during and after volcanism and long after the accumulation of the Tertiary sediments in the Salmon Basin. The long-continued erosion produced a surface of subdued relief, remnants of which are preserved in many parts of the region. This younger surface has since been intricately dissected, showing evidence of a complicated erosional history. During late erosional stages, the region was twice visited by glaciers, each of which left its mark on the topography.

OLD EROSION SURFACES

Pre-Kinnikinic surface

Although not present in the North Fork quadrangle, the Kinnikinic quartzite nearby serves to mark a lower Paleozoic erosion surface beneath the folded Ordovician quartzite. This old surface, carved across the broadly-folded, Precambrian Beltian rocks, is the earliest evidence of land form development within the region. The surface is reported to have had a slight to moderate relief (Shockey, 1937, p. 25) and even considerable local relief (Scholten, 1957).

Pre-Kriley surface

The erosion surface under the Kriley Formation is the earliest of which there is actual record within the quadrangle. Present exposures of the Kriley Formation along the east side of the Salmon River indicate that the formation accumulated on the broad floors of quite mature valleys carved in the underlying Lemhi Quartzite (pl. 7 B). The old surface apparently had only moderate relief, locally no more than a few hundred feet.

Until the age of the formation is definitely established, the erosion surface cannot be accurately dated. Should the formation prove to be the equivalent of the Beaverhead conglomerate (Paleocene), then the erosion surface would have developed during the Laramide orogeny between the time of the northeast folding and the later northwest folding and thrusting. Even should the formation be post-Laramide, the surface would still be older than the one on which the Challis Volcanics accumulated.
Pre-Challis surface

Little of the pre-Challis erosion surface is recognizable within the North Fork quadrangle. Prior to the extrusion of the Challis Volcanics, erosion had stripped away much of the Kriley Formation and had carved valleys and canyons as deep and as steep as those of today (pl. 8 A). The volcanics filled these valleys to spread over remnants of the old surface remaining between them; the flows and pyroclastic may have buried all but the higher summits of the present Beaverhead Range.

Mid-Tertiary surfaces

The angular unconformities separating the several, post-Challis, sedimentary formations indicate much crustal unrest during mid-Tertiary time and correspondingly much, interrupted erosional and depositional activity. Each unconformity marks an episode of uplift and erosion, with the local development of an erosional surface which then became the floor on which the succeeding sedimentary formations accumulated. Thus there are as many of these mid-Tertiary surfaces as there are sedimentary formations. They may be referred to as the pre-Kenney, pre-Geertson, and pre-Kirtley surfaces. Because these surfaces are largely restricted to the area of the Salmon Basin, they are probably local in character and not recognizable beyond its borders. The surfaces apparently possessed low to moderate relief, but the pre-Geertson surface was notably hilly.

YOUNGER EROSION SURFACES

Pliocene surface

After deposition of the Kirtley Formation, erosion apparently continued through much of Pliocene time to produce a surface of subdued relief that was widespread over much of south-central Idaho. Because the surface is so marred in the North Fork quadrangle by later sculpturing, it is difficult to recognize. Some small remnants of old topography remain in the Beaverhead Range, some distance below the levels of the surrounding ridges at altitudes just under 8,000 feet. Some of these remnants are greatly modified by subsequent glacial erosion. The surface is much better and much more extensively preserved in the Salmon River Mountains west of the quadrangle, where the high divide along the boundary of the quadrangle between the Salmon River and Moose and Dump Creeks is a part of the old surface. Westward and southward the surface, carved across volcanics and older rocks, is usually recognizable by the general accordance of ridge levels, although in places there remain sizable, little-modified remnants of the surface itself.

Later surfaces

The area contains an incomplete record of a complicated sequence of geomorphic events developed since the formation of
A. CANYON EROSION SURFACE BENEATH THE CHALLIS VOLCANICS

Picture shows the steep canyon-wall contact between the light-colored rocks of the Challis volcanics on the left and the darker-colored beds of Lemhi quartzite on the right. Salmon River in the foreground; Salmon River Mountains on the left.

B. WISCONSIN GLACIAL FEATURES

Cirque and glaciated valley at the head of the South Fork of Sheep Creek, the product of late Pleistocene, Wisconsin glaciation. Cirque nestles against the Continental Divide.
the Pliocene erosion surface. These events, associated with dissection of the Pliocene erosion surface, are not yet completely understood, although for the most part, they appear to reflect more or less extended interruptions of the dissectional process. The events are largely recorded by bermlike erosion surfaces and high-level benches on the slopes bordering the Salmon Basin and the major stream valleys. Some of the berms may be independent of the present canyons, but others bordering the present drainage form more modern ridge terraces. Each individual berm is separated from nearby berms of different dates by slopes much steeper than any within the berm itself. The berms or benches look like a series of giant steps on the ridges that extend back from the main streams. These steps are particularly conspicuous along the Salmon River Mountain slope. Most of these features doubtless represent minor steps in the intermittent progress of erosion.

The most notable surface is the one in which the Salmon River has entrenched its meanders as it enters its canyon not far above the mouth of Boyle Creek. The surface represents an old valley floor in a mature stage of development, indicating a pause of considerable extent in the downward cutting of the Salmon River.

SALMON BASIN

As a geomorphic feature, the Salmon Basin must have had its inception far back in Tertiary time when streams adjusted their courses along the structurally weak zones determined by the major northwest, high-angle faults (both thrust and normal), and locally by more northerly-trending faults. It probably existed then as a broad, lowland valley rather than as a basin. It was, however, rather deeply entrenched by streams prior to Challis volcanism. After the extravasation of the Challis Volcanics, it began to assume its more modern, basin-like aspect as the accumulation of the younger Tertiary sediments began. Renewed faulting, in part along earlier fault lines, probably blocked off the Beaverhead Range and also fixed the local boundary of the Salmon River Mountains. This faulting provided the setting for vigorous erosion of the land bordering the newly aligned sides of the basin as well as for torrential accumulation of Kenney sediments within the basin itself. Repeated structural adjustments along these earlier established zones of weakness apparently maintained the basin and influenced the later accumulation of Geertson and Kirtley sediments. The basin aspect was probably not so obvious by the end of Tertiary time when the region had been bevelled by the Pliocene erosion surface; but when uplift followed, perhaps accompanied by renewed movement along the older border faults, erosion soon cut deeply into the little-resistant basin beds to re-etch the basin into its present prominent form.
DRAINAGE DEVELOPMENT

Pre-Challis drainage

The pre-Challis drainage is revealed by the pattern of volcanic rocks that filled the valleys carved in the old, pre-Challis erosion surface. Because the main belt of volcanics, which emerges from beneath the cover of Kenney and younger formations near the northern end of the Salmon Basin, becomes progressively narrower toward the north end of the quadrangle, the volcanics must have occupied a valley with headwaters to the north, one carved, therefore, by a stream which flowed in a southeasterly direction. This direction of flow accords with what is known of the pre-Challis drainage in nearby areas (Shockey, 1957, p. 25).

There is no extant evidence to indicate the direction of drainage which produced the pre-Challis erosion surface, but the rejuvenated drainage prior to volcanic extrusions reveals a marked control by structural lines of weakness. It is therefore probable that some of the drainage on the old erosion surface had been adjusted by structural trends to the southeast.

Post-Challis drainage

The abundance of conglomerate in the Kenney Formation and the local dominance of conglomerate in the Geertson (actually a fango-
glomerate), in the North Fork quadrangle, indicate that the drain-
age continued from a northerly direction for some time after Chal-
lis volcanism. The present alignments of the North Fork of the Salmon River and many of the smaller streams may suggest that some of the drainage has persisted in a southerly direction to the pre-
time.

The course taken by the drainage from the Salmon Basin during mid-Tertiary time has not been definitely established, but may have been on to the southeast, perhaps along the Lemhi-Birch Creek corridor. More recent events have completely disorganized the older, post-Challis drainage system, perhaps during the later part of the Pliocene when trunk streams had become established in a northeasterly direction (Anderson, 1947, p. 51-57).

Present drainage

The present drainage pattern is an adaption and modification of the one that apparently existed at the completion of the late Tertiary or Pliocene erosion surface. The general northeasterly alignment of the upper courses of the Salmon River, Lost River, and the former Arco River indicates that the regional drainage had become established in a northeasterly direction on the Plio-
gene erosion surface (Anderson, 1947, p. 51-57). When this regional pattern was disrupted by crustal disturbances at the close of the Tertiary, the northeast courses of the Lost and Arco rivers were defeated by the rising mountain blocks across their paths. The Salmon River continued its course across the rising,
FORMER COURSE OF THE SALMON RIVER ACROSS THE BEAVERHEAD RANGE

The notch on the skyline at the left of the picture marks the former course of the Salmon River until captured and diverted to the Pacific Ocean in early Quaternary time. In its former course the river flowed northeasterly into Montana and thence probably on to Hudson Bay. The basin beds in the foreground include those of the Kriley formation (K) and the capping Geertson formation (G).
Lemhi Range-Salmon River Mountain complex into the Salmon Basin; later it was forced to abandon its northeasterly course across the Beaverhead Range because of its capture by a vigorous stream, which, working back from the West, took on to itself the entire Salmon River drainage. Prior to its capture, the Salmon River crossed the Salmon Basin; passed through the relatively low gap at the head of Blacktail Creek, between Stein Mountain and the still higher ridges to the east (pl. 9); and thence through the low saddle across the Continental Divide at the head of the North Fork of Sheep Creek or possibly near Big Hole Pass.

Capture of the Salmon River, which must have taken place rather early in the Quaternary, may have been instrumental in the rapid removal of so much of the basin fill during Quaternary time. Some time after its capture the Salmon River temporarily stopped its downward cutting, developed a broad valley floor and meanders, and then entrenched its meanders when the vigorous downcutting was resumed. The cause of the singularly straight, lower course of the North Fork of the Salmon River is not fully understood.

Most of the present drainage in the mountains bordering the Salmon Basin is more or less directly down the frontal slopes, with some tributary development along structural trends. Except in the lower parts of the basin, the area is being vigorously eroded.

GLACIATION

The results of glaciation are evident in both the Beaverhead and Salmon River Mountain groups, but the striking effects associated with ice sculpture are largely restricted to the higher parts of the Beaverhead Range (pl. 4 A). Depositional features on the lower flanks of both groups indicate an earlier, more extensive glaciation whose erosive marks in the higher country have been obliterated by the sculpture of the more recent glaciers. The younger glaciation is considered to be of Wisconsin age.

Pre-Wisconsin glaciation

The deposits associated with the earlier, pre-Wisconsin glaciation are widespread along the eastern slope of the Salmon River Mountains, though less so along the lower flank of the Beaverhead Range (pl. 1). These deposits, occurring as caps on the ridge slopes, are remnants of a once much more extensive cover. They are composed of till or outwash.

The deposits on the Salmon River Mountain slope were apparently made by tongues of ice spilling down from the extensive ice cap that covered the tops of the Salmon River Mountains. This ice brought in a remarkable assemblage of huge, granitic boulders (pl. 6 B), apparently from the Idaho batholith some miles away.
A less extensive ice cap on the crest of the Beaverhead Range left outwash material at the base of the frontal escarpment on the now-relatively-low ridges northwest of Fourth of July Creek. Deposits of till have been recognized along the base of the slope in the Baker quadrangle (Anderson, 1957, p. 19).

These deposits, far to the front of those made by the younger Wisconsin glaciers, were made when the relief was less than it was in Wisconsin time. Hundreds of feet of canyon cutting intervened before the Wisconsin glaciers made their appearance. For this reason, the older deposits remain only on the ridges between the subsequently carved canyons.

**Wisconsin glaciation**

The sculpture by Wisconsin glaciers remains as a striking feature of the present landscape in the higher parts of the Beaverhead Range, though less so near the top of the Salmon River Mountain slope. Most valleys that extend to altitudes above 8,000 feet head in cirques whose stepped floors may hold small lakes (Wallace Lake, at the head of Wallace Creek just outside the southwest corner of the quadrangle, and Skewag Lake near Stein Mountain). Below the cirques the valleys are U-shaped downstream for distances up to five miles (pl. 8 B). Though one of the largest glaciers was in the valley of Carmen Creek, some of the more impressive glacial features are in the upper valleys of Fourth of July and Sheep creeks. In most of the glaciated valleys the glacial deposits retain their characteristic forms.

**TERRACES**

Alluvial terraces are conspicuous features along Carmen and Fourth of July creeks and locally along some of the other streams which emerge from the higher parts of the Beaverhead Range. These terraces, heading against the frontal slope of the range, extend downstream for variable distances, some of them to, and thenceinterruptedly down, the Salmon River. There are three sets of these terraces (pl. 7 A), one rising above the other.

The highest terrace, which has the most restricted distribution, is generally found near the base of the Beaverhead Range, although several small remnants were recognized along the Salmon River. The terrace is most widespread in the Carmen Creek drainage, particularly on the slopes northwest of Carmen Creek and on the north side of Freeman Creek (pl. 1). This terrace stands several hundred feet above the valley floor. A smaller but also conspicuous remnant borders Fourth of July Creek where it emerges from its canyon in the Beaverhead Range (pl. 7 A).

The second terrace, also heading at the base of the steep front of the range, generally extends much farther downstream than the highest terrace. Along Carmen Creek the terrace may be traced almost continuously to the Salmon River and down the river valley.
for more than two miles. Remnants appear close to the mountain front on Boyle Creek, below the high terrace on Fourth of July Creek, and at several points along the Salmon River.

The third, or lowest, terrace is extensively developed along Carmen Creek, where it may be traced from the front of the range to the Salmon River, for about a mile along the river, and from there on, by a few widely separated remnants. The terrace rises less than 20 feet above the valley floor; the Salmon River has done an exceptional job of ridding its canyon of these deposits while the North Fork has removed them altogether. Along streams other than Carmen Creek, the terraces remain only in sheltered locations.

These terraces appear to be more or less closely associated with the Wisconsin glaciation and may represent terraced outwash. Some of the gravels remain as relatively thin veneers on what otherwise are rock-cut terraces formed during pauses in the down-cutting of the region.
HISTORIC GEOLOGY

The geologic history as recorded in the rocks of the North Fork quadrangle is very incomplete. The record goes back to the Precambrian but many gaps occur thereafter, the largest of which covers the whole of Paleozoic time and much of the Mesozoic. Nevertheless, something of the local history during that long interval may be inferred from the events recorded in the surrounding region. After the Mesozoic the record, though more complete, still contains many small gaps, especially through the early and later parts of the Tertiary and during the early part of the Quaternary.

PRECAMBRIAN EVENTS

The local record begins with the thick accumulation of sedimentary materials composing the Lemhi and Swauger Quartzites which are believed to be representatives of the widespread Belt Series laid down in extremely shallow seas or basins that reached down from the Arctic region during late Precambrian time. The accumulation appears to have taken place in a broad, slowly sinking geosyncline in which sedimentation kept pace with subsidence so that seas remained shallow while many thousands of feet of sediments were deposited. The local rocks represent only part of the thick accumulation. In the nearby Leesburg quadrangle more than 10,000 feet of phyllite formation (Shockey, 1957, p. 7-8) appear beneath the impure, gray quartzite, here correlated with the Lemhi Quartzite; and the base of the formation remains unrevealed.

During the accumulation of the phyllitic formation, the seas, then somewhat deeper than later, reflected considerable tectonic instability that favored rapid deposition by turbidity currents (Shockey, 1957, p. 23). Conditions had changed when the impure sands and silts that later became the Lemhi Quartzite were deposited: greater tectonic stability and shallower seas are reflected by the presence of ripple marks and cross bedding in the rocks. Conditions of sedimentation further changed when the Swauger sediments were deposited: the coarser grains that make up so much of the Swauger record more powerful currents than those that deposited the Lemhi beds. Belt rocks younger than the Swauger, which were observed near the North Fork quadrangle, indicate that the thick accumulation of Lemhi and Swauger beds belongs well down in the Belt Series. The shallow, shifting seas of Precambrian time appear to have persisted into the early Paleozoic (Ross, 1947, p. 1153).

PALEOZOIC EVENTS

Although no Paleozoic rocks have been found within the quadrangle, their distribution in the surrounding region makes it certain that the area was covered by Paleozoic seas and that sandy, muddy, and limy materials accumulated probably to considerable
thicknes. The area appears to be along the hinge belt between
the Paleozoic Rocky Mountain geosyncline of Central Idaho and the
cratonic shelf of southwestern Montana, thus along a critical zone
with respect to stratigraphic changes induced by recurrent uplifts
(Scholten, 1957, p. 151-170). Whatever beds may have been depos-
itcd during the Cambrian subsidence were lost by erosion, together
with a thick section of the Belt, during the Skull Canyon distur-
bance or uplift of late Cambrian or early Ordovician time. Beds
of Kinnikinic quartzite of Upper Ordovician age, deposited on the
truncated Belt rocks, have been stripped completely from the North
Fork quadrangle though they remain in other parts of the Beaverhead
Range (Scholten and others, 1955, p. 363) and in the Leesburg quad-
rangle in the Salmon River Mountains (Shockey, 1957, p. 10). The
record in the surrounding region reveals other unconformities
indicating additional, isolated uplifts in Devonian and early or
Middle Mississippian time (Scholten, 1957, p. 151-170); but noth-
ing in or near the North Fork quadrangle bears on events through
the remainder of the Paleozoic.

MESOZOIC EVENTS

The quadrangle has no known record of any events through the
Mesozoic. Central Idaho, as far east as the Montana line, is
thought to have stood above sea level during Mesozoic time (Ross
and Forrester, 1958, p. 32) and to have provided the sediment
deposited in the geosyncline farther to the east. The relative
uplift that began near the end of the Paleozoic in the central
part of the State culminated in major folding during the latter
part of the Mesozoic. There the Nevadan orogeny, in late Jurassic
time, prepared the way for the emplacement of the Idaho batholith
in Cretaceous time, but it is doubtful that the folding associated
with this orogeny and the emplacement of the batholith extended as
far east as the North Fork quadrangle. If the effects of the
Nevadan did reach the area, they have been largely obliterated by
the folds and faults that accompanied the Laramide orogeny at the
close of Cretaceous time.

TERTIARY EVENTS

The beginning of the Tertiary was dominated by the Laramide
orogeny. First yielding to forces acting from a northwesterly
direction, the sedimentary rocks were locally thrown into rather
broad, northeast-trending folds oversteepened to the southeast.
More intensive deformation followed later, when apparently much
stronger forces, redirected from the southwest, produced struc-
tures of northwest-to-north trend, which were superposed on the
earlier northeast structures. The first northwest structures were
folds overturned to the northeast. These folds severely compli-
cated and partly obliterated the structural pattern set up by the
earlier, northwest-southeast forces. Strains created when the
northeast compression was superposed on the earlier structures,
were locally resolved by the shifting of earlier fold trends,
through tightened folding of the more incompetent strata, to a more northerly direction; and by adjustments along high-angle, normal, and reverse faults. Low-angle overthrusting later permitted the northwest folds to override some of the stronger, more competent northeast folds. The low-angle thrusting was then followed by high-angle thrusts of northwesterly trend, which closed the Laramide orogeny in early Eocene time. Locally, conglomerate beds assigned to the Kriley Formation were put down, probably before the last intense phase of the orogeny. Bodies of quartz monzonite and granodiorite, as well as scattered, basic dikes, and perhaps other igneous rocks, were intruded locally during its closing stages.

Following the Laramide orogeny, erosion through middle and late Eocene time reduced the region to comparatively low relief to establish the local drainage in a southeast direction. Uplift, perhaps associated with high-angle, normal, or block faulting, then rejuvenated the drainage, which caused the streams to cut deeply into this old (pre-Challis) erosion surface. When extensive volcanism broke out in Oligocene time, the valleys, as deep as those of today, were filled with the volcanic materials that eventually blanketed much of the region. Prior to volcanism, the high-angle faulting along northwest and north trend lines may have initiated the boundaries of the present mountains and the Salmon Basin. The evidence is not wholly clear, but later, active faulting certainly outlined the basin in which the torrential deposits of Kenney Formation accumulated. Recurrent crustal unrest, probably largely resolved by renewed movement along the border faults, provided the setting for the deposition of the younger Geertson and Kirtley Formations, the latter in middle Miocene time or later. Some intrusive activity occurred after volcanism, perhaps during the interval of crustal instability before the post-Challis sedimentation took place.

After sedimentation ceased in mid-Tertiary time, the region continued to be eroded until, by late Tertiary (Pliocene) time, it had been truncated by an erosion surface of low relief, traversed by streams flowing in a northeasterly direction. This drainage was interrupted in late Pliocene or early Pleistocene time by rapid elevation of the present mountain masses, in part along major high-angle faults.

QUATERNARY EVENTS

As a result of the general uplift in late Tertiary and early Quaternary time, a vigorous stream working back from the west was able to capture the Salmon River, diverting it from its previous northeasterly course around the northwest end of the Beaverhead Range and turning its waters from the Missouri River to the Columbia and the Pacific Ocean. Because this capture increased the available relief, the Salmon River and its tributaries were able to cut deeply into and remove much of the basin fill and to bring the Salmon Basin again into prominence.
After the drainage had become established along present lines and the salient features of the present landscape had begun to take shape, a climatic change caused glaciers to appear on the summits of the Beaverhead Range and Salmon River Mountains and to creep down the slopes, reaching into the Salmon Basin. After pushing down the slopes of the basin, these ice caps, which apparently appeared in early Pleistocene or pre-Wisconsin time, melted back and disappeared.

After the disappearance of these early glaciers, rigorous stream erosion, probably stimulated by further uplift, deepened the valleys and dissected the floor of the Salmon Basin into a hilly surface much as it is today, leaving the early glacial deposits stranded high on the ridges and hill tops.

After as much as a thousand feet of canyon cutting had occurred on the flanks of the basin and the bordering mountains, glaciers reappeared in late Pleistocene (Wisconsin) time along the Continental Divide and on the higher ridges of the Salmon River Mountains. They streamed down the canyons, but failed to reach as far as the earlier glaciers. On their disappearance, they left the mountains much as they are today, with the scallop of cirques along higher crests, particularly conspicuous in the Beaverhead Range; and with broad, U-shaped valleys leading downward from the cirques, pinching to narrow, V-shaped canyons before reaching the mountain edge.

As the streams, swollen by melt waters from these younger glaciers and heavily charged with glacial debris, reached the lower country with its lessened gradient, they were forced to drop much of their load, which built up the valley floors, locally to depths of several hundred feet. Then as the glaciers began to recede, the streams, no longer so overloaded and reduced to more normal size, began the job of removing these alluvial fills. This job of removal was interrupted several times, possibly in response to renewed glacial activity; these interruptions alternately retarded and stimulated erosion so that valleys carved in earlier fill were partly refilled, then partly excavated again, leaving the unremoved fill behind in the form of terraces that today border the valley floors of the principal streams draining into the Salmon Basin from the Beaverhead Range. Erosion since the disappearance of the late Wisconsin glaciers has been negligible, except for removal of older valley fills.
MINERAL RESOURCES

KINDS

The North Fork quadrangle is neither especially endowed with mineral resources nor noted for any considerable mineral production. It contains some gold, lead, thorium, and gravel; but these resources are not receiving much attention at the present time. Gold, the first mineral to attract attention, led to considerable mining activity in the early days but has been mined only intermittently since. Lead, which occurs relatively abundantly in some of the gold deposits, is the metal of chief interest. The presence of thorium was not known until the area was combed by the Geiger counter during the recent widespread search for radioactive minerals. The largest resource is gravel.

GOLD-BEARING LODES

History

Just when the first lode discoveries were made remains buried in the past, but some of the deposits were apparently worked in the eighties and nineties and others in more recent times. Because all work and production has been on a small scale, production data were not compiled.

Character

The gold-bearing lodes are mostly small quartz veins and stringers along narrow zones of fissured and fractured rock, with most of the quartz a filling between the fissure and fracture walls and around fragments of included wall rock. Some of the deposits are simple fissure veins, but others are composite and contain additional seams and stringers of quartz; a few are composed largely of quartz stringers. These single and composite quartz veins are similar to hundreds of others in the general Salmon region. As these deposits contain nothing of commercial value, except the gold, they may be classed as gold-quartz veins and lodes showing moderate temperature characteristics and a rather restricted vertical range of effective mineralization. Most of the early production came from oxidized or partly oxidized ore.

One deposit, unlike the others, comprises a broad zone of brecciated, silicified rock healed by very fine-grained silica containing tiny crystals of pyrite. Having no resemblance to the veins of coarsely crystalline, white quartz characteristic of the other deposits, this deposit is probably of different age and origin.

Geographic and geologic distribution

The widely-scattered gold-quartz veins and lodes show some geographic preference for the Salmon River Mountain slope and the
head of the South Fork of Sheep Creek in the Beaverhead Range. Those on the Salmon River Mountain slope are part of a much larger belt of gold mineralization that spreads south and west into the Salmon and Leesburg quadrangles. Those in the Sheep Creek area are apparently on an extension of the belt, in the Baker quadrangle, which seeks the higher parts of the Beaverhead Range.

The deposits are confined to the older rocks; those in the Beaverhead Range are in the Swauger Quartzite; those on the Salmon River Mountain slope are in the quartz monzonite stock and the Lemhi Quartzite.

**Structural relations**

The veins and lodes are along fissure and fracture zones that show considerable diversity in structural relations, particularly in strike and dip. With few exceptions, the controlling structures trend in a general northwesterly direction; those that do not, trend in a northerly, or less commonly in an easterly, direction. The usual trends in the northwest quadrant are N 10° W, N 35° W, and N 80° W, with dips steeply southwest, or more rarely, northeast. If not northwest, the strikes are N 100°-150° E, or exceptionally N 60° E. Dips are steeply northwest. The nearly east-west trends were observed only in the Beaverhead Range.

Most of the veins and lodes have cross-cutting relations, according with the enclosing strata in neither strike nor dip; but a few do parallel the bedding of the host rock. Most of the directing fissure and fracture zones show minor changes in trend. These changes are of some significance, for the veins and lodes are mostly localized along the zones of changing trend.

The localizing structures appear to be associated with Laramide trends; some with the earlier, northeast deformation but most with the later northwest folding and faulting. Some of the lodes are offset by faults that strike northeast. These faults appear to be related to the mid-Tertiary crustal disturbances. One of these later faults apparently localized the one lode whose mineralogic and textural characteristics are entirely unlike the usual quartz veins and lodes.

**Mineralogy**

The gold-quartz veins have a simple mineralogy. Quartz is the predominant mineral, but below the weathered zone it is generally accompanied by scant sulphides, almost exclusively pyrite. Gold in visible grains is reported in some of the oxidized and unoxidized ore.

The quartz in the fillings is milky white to smoky gray, rather coarsely crystalline, and occurs as massive fillings. The pyrite forms sparse, irregularly-distributed, small granular aggregates and fairly coarse, isolated cubes. In the weathered zone, the quartz, partly stained by iron oxides, contains small
masses of limonitic oxides in openings formerly occupied by pyrite or by pseudomorphs after pyrite.

In the one lode that does not conform, the deposit shows extensive silicification. Gray, very fine-grained, and apparently largely chalcedonic, the quartz owes much of its coloring to minutely disseminated grains of pyrite and arsenopyrite. Quartz of younger age, which occurs as a coating on breccia fragments of the gray quartz, forms fine crystalline crusts or crystal druses on fracture surfaces.

**Occurrence and distribution of ore**

Because they are fillings along zones of complexly fissured and fractured rock, the deposits show much variation in structural occurrence and in distribution of the ore. Some veins composed entirely of massive quartz were observed on the surface; a few of them ranged up to six feet or more thick. Most veins that were observed underground, however, were less than two feet thick, composed largely of small lenses and bunches of quartz with additional quartz as seams and stringers through the remainder of the fracture zone. The ore tends to be bouncy and confined to short shoots. The veins appear to pinch and become impoverished with increasing depth.

**Age and genesis of the deposits**

Because some of the veins lie in the body of quartz monzonite on the Salmon River Mountain slope, the gold-quartz mineralization is later than the emplacement of the stock which, in its apparent relation to Laramide structures, is somewhat younger than the main mass of the Idaho batholith, possibly as young as very late Cretaceous or very early Tertiary. This relation of the stock to Laramide structures makes the mineralization younger than was formerly supposed when it was thought that the granitic rock was as old as the Idaho batholith and that the mineralization was localized by Nevadan rather than by Laramide structures (Anderson, 1956, p. 58, 60; 1957, p. 58).

Because the gold-quartz veins show such a high concentration about the quartz monzonite stock, it is logical to presume that a genetic relationship must exist between them. On this assumption, the mineralization cannot be older than very latest Cretaceous nor younger than early Tertiary.

The one deposit which does not belong with the gold-quartz veins is very similar to the Golden Sunbeam lode in the Yankee Fork district, where the country rock that is mineralized is an extensively silicified tuff belonging to the Challis Volcanics (Anderson, 1949, p. 32-37). There the mineralization is assigned to the mid-Tertiary.
Outlook

Because of their small size, the deposits offer little promise of any large, sustained production. The apparent richness of some of the deposits, however, will continue to encourage small-scale operations. Any deep development is likely to lead to disappointment, because mineralization seems to have a fairly restricted vertical range. Erosion in some cases may have removed all but the roots of the formerly more extensive ore shoots.

Mines and prospects

Lang

The Lang claim, owned by Mrs. J. Benson of Butte, Montana, covers a lode on the high ridge west of the Salmon River near the head of Bobcat Gulch in Sec. 5, T. 23 N., R. 21 E., Boise meridian. Just under the crest of Napoleon Hill, it may be reached by an unmaintained road that follows the ridge from the summit crossing of the Stormy Peak road. Encircling Napoleon Hill, the road ends at the property.

Though the lode was worked in the late thirties, apparently little has been done since 1951. The claim was patented in 1953. The development comprises an adit with about 600 feet of workings (fig. 2). An undetermined amount of work has been done above and below the adit level.

Near the adit, the fairly massive beds of Lemhi Quartzite strike N 40°-50° W and dip 58° SW. A short distance to the south are two conspicuous exposures of quartz monzonite granophyre that are probably younger than the mineralization.

The mineralization is along a conspicuous north to north-northwest zone of shearing up to 6 feet across, which is exposed underground for about 430 feet. Along the more highly mineralized parts, the zone dips about 56° W; but where the mineralization lightens, the dip becomes flatter and the shearing weakens. At one point, the vein is offset about 20 feet by a fault that strikes N 55° E and dips 75° NW.

Along the relatively narrow shear zone are quartz seams up to 8 inches thick, which, with intervening, altered quartzite, comprise vein matter from 6 inches to 3 feet thick. Of the coarse, milky variety, the quartz contains a scanty and somewhat spotty distribution of pyrite.

Shoo Fly

The old Shoo Fly claim, now owned by Howard Sims of Salmon, is reported to mark the first lode location in the general region. On the divide separating Moose Creek from the Salmon River just a few hundred yards north of where the Stormy Peak road crosses into the Moose or Dump Creek drainage, it is in Sec. 21, T. 23 N., R.
FIG. 2. MAP OF THE UNDERGROUND WORKINGS AT THE LANG PROPERTY
21 E., (pl. 1). The property contains some old work that is now completely inaccessible. According to Umpleby (1913, p. 154), the property produced about $75,000 in gold.

The lode on the property was easily discovered, for the surface surrounding the outcrop is strewn with large boulders of white quartz. The quartz in places is reported to occur as irregular lenses. Much of the production came from residual quartz boulders, some of high-grade ore.

Delmar mine

The Delmar mine is just above the Stormy Peak road in Sec. 3, T. 22 N., R. 21 E., (pl. 1). It is the property of the Delmar Mining and Milling Company, incorporated on September 19, 1950 with N. E. Mills and H. O. Klaus, both of Spokane, Washington, as president and secretary respectively. Comprising 18 unpatented claims, the property is presently equipped with a small mill and full mining equipment. The property is an old one but has recently been active. The workings comprise some inaccessible old shafts and adits; recent, bulldozed cuts; and an open, 450-foot crosscut (fig. 3). The more recent work is on quartz showings a short distance west of the old work.

The workings are all in coarsely porphyroblastic quartz monzonite close to the margin of the stock. Extensive bulldozing has uncovered considerable quartz float but has not revealed much more quartz than was exposed by some of the older cuts and shafts. The recent underground work was to develop a prominent, locally high-grade quartz vein, which may be traced on the surface in cuts and in an old shaft for more than 100 feet. The vein strikes N 15° E, dips 65° NW, and measures up to 6 feet thick. It is composed of white, coarse-grained quartz, locally fractured and cemented by a jasperoid silica. The crosscut driven to intercept the vein a short distance below the surface encountered a prominent zone of mashed, gougy granitic rock with the same strike and dip as the vein but with no quartz. Apparently the vein had pinched along the highly gougy part of the fault zone and thus did not appear on the crosscut level. No work has been done to prove or disprove the occurrence of quartz elsewhere along the faulted zone at the crosscut level. Some exploration to the north along the zone might be justified, for most of the quartz in the vein is north of the crosscut.

The principal past production has come from workings several hundred yards east of these showings. The workings include a shaft filled with water to within 50 to 60 feet of the surface; and on the slope a short distance above the shaft, a boarded-up adit driven north into the slope. Open stopes on the ridge above the adit show that a white quartz vein, apparently 1 to 2 feet thick, strikes N 75°-80° W and dips 60° SW. This vein has been further explored by a long cut along the outcrop. Some ore on the dump at the shaft is unoxidized. This ore consists of white, coarse-grained quartz with scattered crystals of pyrite.
Wickham mine

The Wickham mine, owned by Worley Lee and others, of Salmon, Idaho, is on an unnamed stream between lower Diamond and Bird Creeks in Sec. 25, T. 23 N., R. 21 E. (pl. 1). The property may be reached by a steep, narrow, little-used road which begins its ascent from the river at the mouth of Diamond Creek and thence across the ridges northwest to and beyond the property.

The property, five Maverick claims and the Liberty Bell No. 3 claim, has been known for a long time and has been worked intermittently until late years. It is equipped with a mill in the valley a few hundred yards below the mine. The property has a number of workings including surface cuts and adits; but most of the adits, except the one in which the last work was done, are caved. The open adit, on the Maverick No. 1 claim, was mapped (fig. 4). About 350 feet long, this adit has stopes both above and below the level, those above reaching to the surface.

The main workings are in the window of northeast-trending structures but very close to the contact with rocks of northwestly trend. The workings are in phyllite; the open stopes on the surface indicate that the vein strikes about N 35° W and dips vertically to steeply northeast. Judging from the width of the stopes the vein worked could not have been more than 1 to 2 feet thick. The rock along the vein has been bleached and, locally, coarsely sericitized.

The vein is better displayed along the adit, which follows the shearing and fissuring inward from the portal; but not until the fissuring changes its course to a more westerly direction, is there much evidence of mineralization. From there on, the vein zone, 2 to 3 feet thick, has been stoped above the level intermittently for about 140 feet and below the level for not less than 80 feet. The vein is cut off by a prominent, northerly-trending fault about 280 feet from the portal (fig. 4).

The ore consists of small seams and pods of quartz with minor amounts of pyrite. The quartz is coarse and white to glassy gray. It commonly shows ill-defined phyllitic inclusions.

A short adit in the next gulch to the northwest reveals a shear zone 3 to 4 feet thick in phyllitic quartzite. This shear zone strikes N 35° W, dips 40° SW, and appears to be conformable with the bedding. Some pyrite has been leached from the sheared zone.

Rocket-Dolly group

The Rocket-Dolly group is on what was once a smaller tributary of Bird Creek, which, because of fairly recent stream piracy, now flows directly to the Salmon River. Just south of Bird Creek proper, this former tributary and the property along it are in Secs. 23 and 24, T. 23 N., R. 21 E. The road to the group via the Wickham property is no longer accessible.
FIG. 4. MAP OF THE ACCESSIBLE UNDERGROUND WORKINGS AT THE WICKHAM MINE
These patented claims, the Rocket, Seloma, Little Maud, and Dolly, are owned by Joseph Rouker, J. R. Silver, B. T. Richards, and J. C. Bennett, all presumably of Salmon, Idaho. The work on the claims is old and much of the underground is inaccessible. The workings are in two groups several hundred yards apart, one in the main gulch of the valley and the other in a small tributary that joins from the west.

The property covers the contact between the window of north-northeast-trending phyllitic and quartzitic beds and the southwest-dipping northwest-striking, quartzitic beds. The workings in the tributary gulch are in the window of northeast-trending rocks, but those in the main gulch may be just outside the window.

The workings in the tributary gulch comprise a series of old adits, some of which remain open. The lowest adit, more than 100 feet long, shows some stoping above the adit level. It is along a three-foot zone of sheared and mashed quartzite that strikes N 10° W and dips 35° SW. The next two adits are caved, but the dumps show that phyllitic rock was uncovered underground. An inclined winze exposes some of the phyllite just above the caved portal of the second adit. Another winze, or probably a raise from below, is present above the third adit. The vertical distance between this adit and the lowest one, near the bottom of the gulch, is about 100 feet. Another adit, about 50 feet east of the third adit, is driven in phyllitic beds that strike N 10° E and dip 35° NW.

The workings in the main gulch comprise several cuts and an adit, all near the gulch bottom. The adit is open for about 30 feet. Some quartz appears on the dump but the quartz was not observed in place. From the alignment of cuts and the direction of the adit, the vein must strike about N 30° W.

**Bird Creek-Comet Creek properties**

Other lodes in the area are the Forget-Me-Not lode on Bird Creek, owned by Roy E. Johnson, Salmon, Idaho, and a group of patented claims on Comet Creek. These properties were not examined.

**Smitty property**

The Smitty property is near the crest of the ridge east of Blacktail Creek but may extend across the ridge into the drainage of the South Fork of Sheep Creek. The property, in Secs. 34 and 35, T. 25 N., R. 22 E. (pl. 1), is owned by G. S. Franklin and L. K. Franklin, who made the locations in September 1956.

The work on the property comprises a number of bulldozed cuts on the west side of the ridge and may include some old, caved adits in line with the cuts on the east side of the ridge, though the work there was apparently done long ago.

The cuts reveal a narrow vein in white Swauger Quartzite, trending apparently in an easterly direction. The filling consists of white quartz with some widely scattered crystals of pyrite.
Sheep Creek properties

A number of old workings, all caved, occur in the cirque basins at the head of the South Fork of Sheep Creek, mainly in Sec. 35, T. 25 N., R. 22 E. Although the area was apparently quite active at one time and milled an unlearned tonnage of ore, shafts and adits are now caved; the only evidence of former productive activity is a small pile of sacked, unshipped sulfide concentrates.

The rock in the vicinity of the old properties is rather massive, well-bedded Swauger Quartzite whose beds strike about N 80° W and dip 24° NE. The alignment of shafts, adits, and caved stopes indicates that the veins strike about N 80° W. Because veins were not observed in place, their size remains unknown, but fragments or chunks of vein quartz on the surface suggest that they are narrow, perhaps a foot or less. Additional quartz stringers, however, could compose a mineralized zone up to several feet thick. The quartz is the usual white or milky variety, with a scant distribution of sulfides.

White Azalea

The White Azalea claim, owned by Margaret Fowler and T. R. Benedict of Salmon, Idaho, is in a small, steep gulch on the east side of the Salmon River just north of the mouth of Fourth of July Creek in Sec. 35, T. 24 N., R. 21 E. The workings are near and within sight of the highway.

The development comprises two adits, one about 160 feet long in the upper part of the gulch, the other near the highway. The lower adit is caved near the portal, but the dump material indicates that it extends under the upper adit and hence may have a length of a thousand feet or more.

The dark-colored beds of the Lemhi Quartzite have been much disturbed in the vicinity of the property. At the portal of the upper adit, the beds strike N 30° W and dip 40° NE, but not far away the beds strike more westerly, and locally, even northeast.

The upper adit is driven along a rather broad zone of somewhat bleached and brecciated quartzite that has been extensively silicified. Poorly defined, this mineralized zone trends N 60° E and dips steeply northwest to vertical. The quartz associated with the mineralization is very fine-grained, possibly chalcedonic, and contains minutely disseminated grains of pyrite and some arsenopyrite. Actually two generations of quartz are represented: the earlier, very fine-grained quartz darkened by its disseminations of minute, occasionally larger crystals of pyrite; and the later, fine druse crystals coating the surface of breccia fragments of the earlier quartz. Apparently after early brecciation and alteration, the quartzite was cemented and partly replaced by the fine-grained, chalcedonic quartz. With further movement, which also brecciated the fine-grained quartz, the
somewhat larger druse crystals were deposited on the surface of the breccia fragments.

Other properties

Other gold-quartz veins are also present, some of which had considerable work in the early days. Some were prospected by a few cuts and short adits and then apparently abandoned. Others were more extensively explored and developed, then patented, after which work ceased. Because most of these properties are now completely inaccessible, the fact that they are not described individually does not mean that they have less merit than some of those that are described.

PLACERS

Placer operations on a small scale were limited to some work in the upper Wallace Creek drainage on the Salmon River Mountain slope in the vicinity of the Delmar mine and to some work along Sheep Creek at the north margin of the quadrangle. How successful these operations had been was not learned. Some dredging ground is held along lower Sheep Creek but the gravel strip is narrow, only a mile or two long. There may have been some placering at the mouth of Freeman Canyon in the early days.

LEAD DEPOSITS

History

The lead deposits were probably among the earliest discoveries, for the deposits, with bold, conspicuous outcrops, are easily accessible along the base of the Beaverhead Range. They were first located and worked for gold, but gold values were relatively low and the sulfides contained with the gold apparently interfered with gold recovery. Later, some attention was directed to the lead and some was recovered from one of the deposits; but lead production, like gold, has been small. The deposits still continue to attract attention, primarily because of their relatively large size and the hope that their low-grade ores may be amenable to relatively large-scale, low-cost operations.

Character

The lead mineralization is apparently a variant of the gold-quartz mineralization that characterizes the Beaverhead Range, with the local lead deposits containing a notably greater concentration of galena than is usual for the gold deposits. These lead deposits are also considerably larger than the gold-quartz lodes, measuring several tens of feet, even more than a hundred feet, across. Occurring as fillings and replacements along extensive zones of brecciated and otherwise fractured rock, they are accompanied in part by widespread silicification. They were apparently formed by mineralizing solutions of moderate thermal intensity,
under pressure conditions somewhat different from those associated with the probably unrelated, quartz veins in the Salmon River Mountains.

Geographic and geologic distribution

Only two of these lead deposits were observed in the North Fork quadrangle, although others of smaller size noted elsewhere along the Beaverhead Range, have been included and described with the gold deposits (Anderson, 1957, p. 54-64). Both of the local deposits are along the base of the Beaverhead Range, one near the mouth of the canyon of Freeman Creek; the other where Gold Star Gulch, a tributary of the East Fork of Boyle Creek, emerges from the front of the range.

The deposits favor no particular geologic formation. One is contained in the Lomhi Quartzite, the other in a down-faulted block of Swauger Quartzite. Their distribution appears to be structurally, not stratigraphically, controlled.

Structural relations

The lead deposits occupy broad zones of brecciated and otherwise greatly shattered rock close to the base of the range. These zones do not accord with the prevailing northwest-trending structures but are nearly normal thereto. One trends N 70°-80° E and dips steeply southeast; the other trends N 30°-40° E and dips 30°-40° NW. The precise relations that these trends may have to Laramide structures have not been completely determined. Apparently the zone of extensive deformation along the front of the Beaverhead Range has been particularly favorable for the localization of the lead deposits, especially for the deposition of exceptional amounts of quartz.

Mineralogy

The mineralogy of the lead deposits is comparatively simple. As in the gold veins, quartz is by far the most abundant mineral; but with it are noteworthy amounts of galena and variable though generally much lesser amounts of sphalerite, tetrahedrite, chalcocpyrite, and pyrite.

The quartz is white and generally rather coarse-grained, although not so coarse in one of the deposits as in the other. The sulfides are scattered irregularly through the quartz, in part as local disseminations, in part as sporadically distributed small granules, pods, and bunches. Always the most conspicuous sulfide, the galena is coarse-grained with conspicuous cubic cleavage, except near Freeman Creek where all minerals tend to be somewhat finer-grained. The sphalerite is light-colored. The other minerals have no unusual features. In Gold Star Gulch the sulfides tend to fill openings between quartz crystals but near Freeman Creek the sulfides replace the quartz along fractures.
The quartz in the weathered zone is partly stained by yellowish and brownish iron oxides and that in Gold Star Gulch, by vivid greenish and bluish patches of malachite and azurite as well. Sulfides that appear in the outcrop show incomplete oxidation. Residual grains and masses of galena are commonly crusted with anglesite and cerussite and in places with pyromorphite as well. The malachite and azurite have formed by the weathering of the chalcopyrite and, perhaps, by the tetrahedrite. The weathered products are far more conspicuous in Gold Star Gulch than in the Freeman Creek area.

**Occurrence and distribution of the ore**

In the Gold Star Gulch area, the quartz and sulfides fill the openings along a broad zone of brecciated quartzite, locally as much as 40 feet across, with the quartz much more widely dispersed than the sulfides. The latter show an irregular, somewhat sporadic distribution, though in small areas they form zones of possible milling ore.

In the Freeman Creek area, the phyllitic quartzites across a zone perhaps several hundred feet thick have been extensively silicified and then shattered, with the shattered rock cemented by small quartz stringers that contain in places scattered grains as well as more closely packed disseminations of galena and lesser amounts of associated minerals. In some places the sulfides form discontinuous pods and veinlets up to two inches thick but nowhere form massive ore. Most of the sulfides have been leached from the immediate outcrop. Little more can be said about the occurrence and distribution of the ore until more work has been done below the surface. Though the disseminated galena appears to form sizable bodies of low-grade ore, possibly containing up to two percent lead, much systematic exploration and sampling is needed before estimates of grade and amount of ore can be made.

**Age and genesis of the deposits**

Because these deposits are close to the Carmen Creek stock, they may have some genetic relationship to this body of granodiorite. Except for some similarity in the character of the quartz, these deposits are quite unlike those found in, about, and in genetic association with the quartz monzonite stock on the Salmon River Mountain slope. Although the Carmen Creek granodiorite is thought to be somewhat older than the quartz monzonite across the quadrangle, the mineralization is still no older than early Tertiary.

**Outlook**

Until the demand for lead becomes more pressing and the price considerably higher than it is at present, the lead deposits are not likely to receive much consideration. Because the lead is contained in such large volumes of quartz, low-cost mining and milling are essential, though the small content of precious metals that these deposits contain will partly offset costs.
Silver Star property

Properties

The Silver Star property is in Gold Star Gulch, a tributary of the East Fork of Boyle Creek, at the base of the Beaverhead Range in Secs. 10 and 11, T. 23 N., R. 22 E., Boise meridian. The conspicuous surface mineralization made the property an early location that was long the center of considerable local interest. Multiple ownership in later years hindered work on the property.

The development comprises a sizable open cut along the bold outcrop atop a low ridge extending out in a westerly direction from the lower front of the Beaverhead Range, and a 150-foot adit drift driven easterly from the end of the ridge at gulch level. The property was once equipped with a small gravity concentrator; but the mill was apparently dismantled long ago. Some of the old mill tailings were apparently tabbed at a more recent date.

The property covers a downfaulted block of Swauger Quartzite along the base of the Beaverhead Range, close to the major Beaverhead fault. The mineralization is along a broad zone of extensively shattered and brecciated quartzite, 40 to 50 feet wide, that strikes N 70°-80° E and dips steeply southeast.

The breccia along the zone has been cemented by white, fairly coarse-grained, partly drusy quartz; by scattered granules and small pods of fairly coarse-grained cubic galena; and by lesser amounts of sphalerite, tetrahedrite, chalcopyrite, and pyrite. These minerals, which have an irregular, somewhat sporadic distribution, nowhere combine to form massive ore. These sulfides have not been entirely removed from the outcrop. Some of the galena is partly altered to anglesite and cerussite, and in some places, to pyromorphite. Much of the sphalerite has been leached from the cappings; what remains has a light color, indicating little iron. The tetrahedrite and chalcopyrite have been mostly lost, but they have given rise to conspicuous stains and coatings of bluish azurite and greenish malachite. Because of the low content of pyrite and chalcopyrite, there is little brownish limonitic staining: the azurite and malachite remain as the most strikingly conspicuous minerals in the outcrop.

Dike mine

The Dike mine is on the lower frontal slope of the Beaverhead Range in the far southeast corner of the quadrangle in Sec. 5, T. 22 N., R. 23 E. It borders the prominent gulch carved along the base of the range just south of Freeman Creek.

The old mine has not been worked for many years, except for annual assessments. The mill has long been dismantled. The development has been slight, consisting of five short adits and a number of small cuts, some made during the past several years. Little work is needed to explore the property, for erosion has
conveniently stripped away the hanging wall to the gulch bottom, leaving the deposit fully exposed for about 1,000 feet along the strike and for an even greater distance up the mountain slope.

The deposit consists of a broad zone of silicified, phyllitic quartzite (Lehni Quartzite). This zone strikes N 30°-40° E, dips 30°-40° NW, and throughout its length controls the frontal slope of the range, causing a local departure from the otherwise prevailing northwest trend of the range. The silicified zone appears to be more than 100 feet wide, for none of the short adits passes into unaltered rock of the footwall.

This silicified zone has been shattered; the shattered rock has been cut and healed by small, ramifying quartz stringers containing irregularly scattered grains and disseminations of galena along with lesser, inconspicuous grains of sphalerite, pyrite, and chalcopyrite. The sulfide minerals, largely leached from the surface exposures, appear in the short adits and the shallow cuts. In some places, the sulfides form discontinuous pods and veinlets up to two inches thick, but these exceptional concentrations are widely scattered and only occasionally coalesce into slightly larger masses or become more closely spaced. Much of the galena, and the other sulfides, occur as small, disseminated grains in the fractured, silicified rock.

The quartz in the seams and irregular stringers is not very coarse-grained. Fractured before the sulfides were introduced, the quartz has been partly replaced by the galena and less abundant, associated minerals.

Because of its large size, the deposit contains quantities of lead and zinc; but the ore is too low grade for profitable mining and metal recovery under present economic conditions.

THORITE DEPOSITS

Location and accessibility

The thorite deposits are in the Diamond Creek area about six to eight air miles north-northwest of Salmon. They are about half way up the east slope of the Salmon River Mountains, mainly on ridges bordering tributaries of Diamond Creek and in shallow gulches on the slope between Diamond Creek and Wallace Creek (pl. 1). The deposits are confined to a small area of probably less than three square miles, mostly in the southeastern part of T. 23 N., R. 19 E., but possibly extending into T. 22 N., R. 19 E., Boise meridian.

Though not readily accessible, the deposits may be reached from the Stormy Peak road, which leaves the main highway about three miles north of Salmon. Because the Stormy Peak road passes a mile or so above the deposits, to reach them one must drop down a broad, tree-covered ridge between Wallace and Diamond creeks,
over a poorly marked road or jeep trail. The route is across several steep gulches and, unless the trip is made in the company of the owners or with someone else familiar with the area, the deposits may escape attention.

**Character of the deposits**

Much like those in the Lemhi Pass area (Anderson, 1958, p. 45-74), the deposits include mineralized shear zones and gold-quartz veins, with appreciable concentrations of thorite and rare earth elements. Because of pronounced oxidation associated with weathering, the deposits contain an abundance of hydrous iron oxides, chiefly goethite, which makes it difficult to observe the true character of the mineralization. The microscope, however, confirms their resemblance to the Lemhi Pass deposits, disclosing that the thorite and associated minerals are chiefly disseminated replacements of sheared and fissured rock, and locally are minor additions to fractures in older, gold-quartz veins.

**Geologic setting**

The deposits are in and on the lower side of the quartz monzonite stock, partly in the window of northeasterly-trending Belt rocks. Outside the body of coarse-grained quartz monzonite, the immediate country rock is largely dark-gray, micaceous quartzite with some zones of schistose rock, particularly in and along some of the mineralized zones. The rocks are broken by small faults of northeasterly strike, some of which are mineralized.

**Structural relations**

All the deposits strike in the northeast quadrant. They show no general parallelism. Some occupy shear and fissure zones that trend N 10° E; some, N 25° E; still others, N 35° E; and at least one, N 50° E. They all dip northwest at moderate to steep angles.

Most of the zones of sheared and fissured rock are not very broad; the mineralized bodies within are less than four feet wide and less than a foot in some places. Some of the mineralized zones are short, a few tens of feet; others may be some hundreds of feet long. The shearing and fissuring are about as pronounced in the granitic rock as in the schistose rocks and quartzites.

**Mineralogy**

The minerals identified in the deposits are thorite, monazite, xenotime(?), apatite, specular hematite, barite, fluorite, feldspar, and quartz. Few of these minerals are recognizable without the microscope: though the quartz is usually visible, the monazite, specular hematite, barite, and feldspar can rarely be recognized by the unaided eye.
The minerals are present in variable amounts. In some places the thorite is notably abundant, though not so abundant as the monazite and specular hematite. The barite, though somewhat sporadic in its distribution, is in most places well-represented. The other minerals are generally subordinate, but all in all, the proportions and distribution of the minerals are not much different from those found at Lemhi Pass. To describe the minerals, their characteristics, and relations individually would be needless repetition of what has already been written about them in the Lemhi Pass area (Anderson, 1938, p. 51-53).

The mineral relations indicate that the thorite is the earliest mineral and that the meager quartz is the latest, with monazite, specularite, barite, and feldspar falling successively between. Though the apatite and xenotime (?) are closely associated with the monazite, their exact place in the sequence has not been established.

General features of the deposits

The deposits have been little prospected and the scattered exposures provide inadequate data on the persistence of the mineralization along the shear and fissure zones. Some of the deposits, hundreds of feet long, are two to three feet, occasionally up to four feet, thick. Others, apparently much shorter, are less than a foot thick. Where exposed in cuts, most of the deposits show strong radioactivity and variable amounts of thorite and associated minerals; but whether the mineralization holds up from one exposure to another or is mostly localized in the immediate vicinity of the prospected ground is not definitely known. Some deposits appear to show rather continuous mineralization but with spotty distribution of individual minerals.

Abundant yellowish and brownish hydrous iron oxides along the vein and shear zones may serve as guides to the presence of thorite and associated rare earth minerals. The highest radioactivity seems restricted largely to brownish, jasperoid-like material, in most places associated with compact and powdery goethite. Under the microscope the hard, jasperoid-like material reveals much of the thorite and associated minerals.

Because the deposits were not sampled during the present investigation, the grade or tenor of the material was not definitely established; but the microscopic work tends to confirm statements by G. E. Shoup that samples he took across 3-foot widths of the deposit on the Contact group, contain up to 0.75 percent thorium and four percent rare earth oxides. He also reports some uranium in the deposits.

Outlook

More exploration is needed to determine the size of the deposits and the grade of the thorium-bearing material. The area appears to be worth more attention than it has received.
Properties

Contact

The Contact group of claims is on Diamond Creek, mainly in Sec. 26, T. 23 N., R. 21 E., but also partly in the southeast quarter of Section 27. The group of twelve Contact claims and three Bell claims are owned by P. Reddington, F. Van Meter, and G. E. Shoup of Salmon, Idaho. These claims cover an old, gold-quartz location, long abandoned and subsequently relocated after the discovery of radioactive and rare earth minerals. The old work comprises several short adits and shafts, mostly caved. The new work is restricted to some bulldozed cuts.

Thorium and rare earth minerals are exposed on several of the claims, with the most noteworthy showings on the Bell No. 1 claim and on the Contact No. 1 and No. 2 claims. These showings are in the folded and faulted schistose and quartzitic Belt rocks within a few hundred yards of the quartz monzonite contact. The Belt strata locally strike about N 35° E, and dip 45° NW and are cut by faults that trend about N 10° E and, in part, dip 33° NW.

The exposure on the Bell No. 1 claim is along the road on the ridge crest between the forks of Diamond Creek, about 200 yards east of the quartz monzonite contact. Rusty cropings are exposed in the road cut, but the best exposures are in a bulldozed cut just below the road turn on the north edge of the ridge. The cut and road reveal a broad mineralized zone of apparent N 10° E trend. The highly-oxidized material along the zone contains abundant, brownish, limonitic oxides (chiefly goethite); some bands of brownish, jasperoid-like material; scattered thin seams of quartz; and irregular spots of reddish hematite. This zone of more intense mineralization measures about 4 feet across. Microscopic examination of the jasperoid-like material reveals variable amounts of monazite, thorite, specularite, apatite, barite, microcline, and quartz. The notably abundant barite may be recognized in some of the material without the aid of the microscope.

On the Contact No. 2 claim, the mineralized zone is exposed along a 44-foot adit and in a small shaft 285 feet farther up the slope. The adit is driven into a schistose zone about 10 feet wide, bordered by more massive, micaceous quartzite. The schist strikes N 35° E, dips 35° NW, and as exposed in the adit, is cut by a mineralized fault which strikes N 10° E and dips 33° NW. This fault contains a vein of highly oxidized material up to 2 feet thick, above a band of footwall gouge. Microscopic examination of this brownish material discloses mostly goethite, with areas abundantly rich in specularite, thorite, and monazite. A sample across 3 feet of this weathered material is reported by Mr. Shoup to contain 0.31 percent U₃O₈, 0.75 percent ThO₂, and 4.0 percent rare earth oxides.

The vein in the shallow shaft is about four feet thick, and shows high radioactivity. A microscopic study of white and gray
quartz composing the vein, which is locally seamed with limonitic oxides, reveals conspicuous amounts of monazite occurring as disseminated crystals, as crystal clusters, as well as some specularite and thorite. These mineral aggregates are extensively permeated by younger quartz, which tends to eliminate the specularite and thorite but not the monazite. Samples taken at the shaft across three feet of the deposit are reported to contain 0.07 percent U₃O₈, 0.38 percent ThO₂, and 2.01 percent rare earth oxides.

At the caved adit on the No. 1 claim across a shallow gulch northwest of the adit on the No. 2 claim, a large, bulldozed cut has uncovered a broad zone of sheared, schistose rock that strikes N 35° E, dips 45° NW, and shows considerable radioactivity. The mineralization appears to be similar to that on the No. 2 claim.

Simer

The Simer is in a small, shallow gulch just south of the Diamond Creek drainage, perhaps a mile south-southwest of the Contact No. 2 claim. The property, along the jeep road to the Contact, comprises approximately 10 claims owned by Teal and Waterman of Salmon. The work consists of several large and small bulldozed cuts.

The deposits on this property comprise three veins in granite the main one in a large cut in the upper part of the gulch. This vein strikes N 50° E, and dips 60° NW. It contains two to three feet of highly radioactive, jasper-like rock, which, examined microscopically, shows abundant monazite and variable amounts of barite, purplish and colorless fluorite, and quartz.

A short distance above, a second and much smaller vein strikes N 10° E and dips northwest at a moderate angle. This vein, which apparently does not extend beyond the limits of a 30-foot cut, contains up to eight inches of an oxidized, jasperoid-like filling.

The third vein is exposed in several small cuts lower in the gulch. This vein, about a foot thick, lies within a zone of sheared and mineralized, granitic rock about five feet across. This vein strikes about N 35° E. No material was collected for microscopical study.

Lucky

The Lucky group is just over the ridge north of Wallace Creek, also on the jeep road to the Contact property. This group, known as the Frank Burch property, comprises 10 claims on ground originally located and worked for gold. The work consists of an eight-foot shaft and a number of cuts.

The Lucky group has both gold-quartz and thorium veins, in part along the same zones of shearing. These are contained in quartz monzonite.
Most of the work has been on a gold-quartz vein which strikes N 25° E and dips 84° NW. This vein is about three feet thick at the shaft but thins to about a foot in a cut some 50 feet down the slope. Just beyond the cut, the vein appears to pinch out altogether. In the cut, the vein, along the footwall of a four-foot thick zone of fractured granitic rock, is composed of white quartz with scattered sprinklings of pyrite. Here and there the vein shows some radioactivity, especially in the vicinity of small bodies of brownish, jasperoid-like material.

Other cuts not aligned with the quartz vein show a high background count and in places high radioactivity. As elsewhere, the radioactivity appears to be largely restricted to brownish, jasperoidal material and not to white vein quartz.

GRAVEL DEPOSITS

Gravel supplies far exceed local needs. Some gravel has been used in bridge and highway building, and very locally in foundations. Almost unlimited quantities are available in the gravel terraces as well as along both the main valley bottoms, and on valley floors, where alluvial fan deposits spread out from the mouths of bordering gulches. Much gravel is also available where weathering has induced disintegration of the conglomerates in the Kenney and Geertson Formations.


PLATE 1. GEOLOGIC MAP OF THE NORTH FORK QUADRANGLE